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A Manual for the Performance of Protective Equipment Fit-Mapping

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Human Effectiveness Directorate
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This fit mapping manual is intended to offer detailed up-to-date guidance for preparing, performing and analyzing fit evaluations for most types of clothing and protective equipment. The term "Fit Mapping" is used to differentiate it from the traditional fit testing that has been conducted primarily for determining an accommodation rate and verification of requirements. This manual addresses: 1) definition of the "Fit Criteria (Concept of fit)" for a test item, 2) performing a fit evaluation, 3) analysis of the results, and finally, how to apply these results to the manufacturing process. Therefore, this fit mapping manual offers the basic knowledge needed to evaluate various types of equipment by presenting a step by step procedure.

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PREFACE

This fit mapping manual is intended to offer detailed up-to-date guidance for preparing, performing and analyzing fit evaluations for most types of clothing and protective equipment. The term “Fit Mapping” is used to differentiate it from the traditional fit testing that has been conducted primarily for determining an accommodation rate and verification of requirements. In fact, fit evaluations are needed for much more than just rating a size roll. Fit testing results should also be iteratively applied in sequential modification stages for design and size roll improvement. In addition, the results can also be used to refine cost estimates of the systems. Hence, fit mapping is a bigger concept that includes traditional fit testing and its product (i.e. an accommodation rate) as a part of fit evaluation process. This manual addresses: 1) definition of the Fit Criteria (“concept of fit”) for a test item, 2) performing a fit evaluation, 3) analysis of the results, and finally, how to apply these results to the manufacturing process. Therefore, this fit mapping manual offers the basic knowledge needed to evaluate various types of equipment by presenting a step by step procedure.

For protective equipment, a fit definition must consider mission effectiveness, safety, and functional aspects as well as comfort and aesthetic appearance. There are four aspects of fit to assess: 1) static, 2) dynamic, 3) integration/compatibility, and 4) occupation specific assessments. When constructing the Fit Criteria (“Concept of Fit”) for a test item, it is important that the end-users functional requirements are captured and translated into measurable entities. This is how fit-mapping results reveal the relationship between anthropometric ranges and garment dimensions. These results can then be used to suggest any pattern or size roll modifications, make tariff calculations, and determine the accommodation rate for the item.

Fit mapping evaluations include: fit evaluators, test item inspection, and the actual size assessment. Most importantly, in this manual, fit evaluation methods are introduced and discussed using two different approaches, objective and subjective measures. Traditionally, fit tests were performed subjectively by experts’ visual inspection. However, to quantify the outcome of a fit evaluation, it is necessary to assess fit in an objective manner by recording the outcome by an actual measurement quantity. This manual introduces and shows objective measures by demonstrating ease and line measurements. Moreover, the advantages and disadvantages of using a 3-D scanner for a fit evaluation are presented for both objective and subjective measurements. Finally, a combined approach, using traditional methods augmented with 3-D scanning is suggested.

This manual also reviews issues related to data analysis. This includes: data input, extracting key dimensions for a size roll, issues related to sampling, and the target population. The correct proportioning of an item for a given body size or type also requires knowledge about the relationship between the body and the fit of the item. For that reason, fit evaluation results should be examined relative to anthropometric survey data for the user population. In that way, size charts with the body size ranges fitting into each gear size can be produced. This manual also presents the final products for an example fit-mapping analysis - an accommodation rate, a size evaluation for a pattern modification, and a size tariff and size roll. The analyses introduced are less of a common statistical approach - but rather are characterized by procedural steps intended to arrive at the needed products. The steps show how to organize the fit evaluation results to calculate the portion of the population covered (Accommodation Rate), where to look to identify fit problems (Size Evaluation), how to apply the fit-mapping results to make pattern modifications, and finally, how to develop a size-roll. In addition, one of the steps allows calculation of the number of sizes needed to fit the aircrew population (Tariff).

1. INTRODUCTION

1.1. What is Fit-mapping?

Fit-mapping is a process that quantitatively characterizes the relationship between the garment being tested and its target population. The process of Fit-mapping applies fit-testing results in an iterative fashion to improve the fit quality of the tested item by classifying who *does* and *does not* fit well in the test sizes. Given a quantitative and functional definition of "Fit", accommodation rates can be calculated for a target population, and unnecessary or additional sizes can be identified. Fit-mapping results can also provide design and reshaping recommendations to make the product fit better overall (Robinette and Hudson, 2006). Fit-mapping analysis ensures maximizing the accommodation of the population of users with the minimum number of sizes and adjustments, and produces a size chart to help the wearers when they select their sizes. This chart is also called a *size roll* (refer to section 4.3.3.C Size evaluation). Finally, it guides how many of each size to produce/purchase (i.e. *the tariff*).

This manual defines "Fit-testing" and "Fit-mapping" differently. In a report on guidelines for Fit-testing, McConville et. al. (1979) acknowledges that "...the success of a sizing system can only be established by a hands-on fit test..." The main purpose of McConville's report was to document methods for Fit-testing that verify a large percentage of a population can get an acceptable fit. This reflects the fact that Fit-testing in the past has been conducted primarily for determining the accommodation rate and verification of requirements. In fact, evaluations of fit are needed for much more than just rating a size roll.

Fit-testing results should also be iteratively applied, in sequential modification stages, for design and size roll improvement. In addition, the results can also be used to refine cost estimates, as well as performance effectiveness, of the systems (Robinette, 1996). Thus, to differentiate this expanded definition from traditional fit-testing, we use the term "Fit-mapping." Fit-mapping is a bigger concept that includes traditional Fit-testing and its product (i.e. the accommodation rate) as a part of the Fit-mapping process (Figure 1).

Testing the "Fit" of an item is known to be rather challenging work given that it is a hard concept to completely define. The most confounding factor is that the concept of "Fit" is highly related to changing fashions and personal preferences, which are free to vary and are unpredictable. In the past, "Fit" testing performed by "expert visual inspection" has been a reasonable evaluation approach in many studies. This is due to the fact that fit is difficult to define quantitatively. Thus, it is generally believed that fit should be tested by experts in order to gather consistent and reliable data across subjects. However, if focus is placed on the "Fit" of special garments (i.e. protective equipment) which are not easily influenced by current fashion or personal preference, a **functional** and **measurable** definition of fit for each item can be produced so that consistent and quantitative fit evaluations are possible even by non-expert judges.

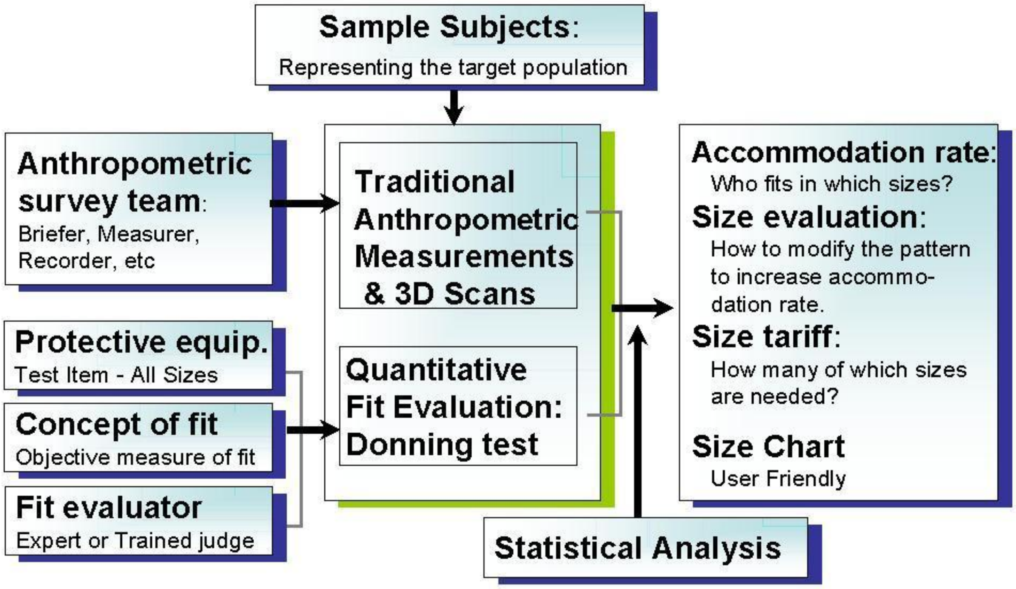


Figure 1. Fit-mapping process overview

1.2. Scope of this Manual

This manual is intended to offer detailed up-to-date guidance for preparing, performing and analyzing fit-tests for most types of clothing and protective equipment. It addresses: 1) definition of the "fit criteria (concept of fit)" for a test item, 2) performing a fit evaluation, 3) analysis and interpretation of the results, and finally, 4) how to apply these results to optimize the product design. In other words, this manual offers the basic knowledge needed to evaluate various types of equipment by presenting a step by step procedure.

Section 2 is devoted to introduction of a method for developing fit criteria for a test item. Various definitions of "Fit" from the literature are introduced along with associated fit characteristics. The main purpose of this section is to introduce various aspects of the fit assessment process and to demonstrate how quantitative and measurable fit criteria for a test item can be developed.

Section 3 organizes the issues related to fit evaluation. This includes: fit evaluators, item inspection, and the actual size assessment. Most importantly, fit evaluation methods are introduced and the advantages and disadvantages of using a 3-D scanner for fit-testing are presented.

Section 4 presents a method for fit-mapping data analysis. The analyses introduced in this section are not like most common statistical analysis (i.e. ANOVA, Regression, or any other Univariate analyses) but are procedural steps that show how to organize the fit evaluation results and where to look to identify fit problems. Other topics include sampling, data input, extracting key dimensions for the size roll, and how to apply the fit-mapping results to the modification of the size-roll and tariff.

The correct proportioning of an item for a given body-size or type also requires knowledge about the relationship between the body and fit of the item. For that reason, fit evaluation results are examined relative to anthropometric survey data for the user

population. In that way, size charts with the body-size ranges fitting into each gear size can be produced.

General information on anthropometric surveys is given in APPENDIX A.

PREPARING FOR A FIT TEST

When examples are used to clarify concepts in this manual, the current CWU 27/P flight suit or prototype flight suit illustrations, and results of a prototype flight fit assessment are used. Potential testing items that this manual could cover include (at least) the current USAF protective equipment suite. That ensemble includes: the helmet, oral/nasal mask, survival vest, Anti G-suit, immersion suit, winter jacket, and flight suit

2. FIT-MAPPING CRITERIA

This chapter introduces the definition of "Fit" in terms of its characteristics and aspects, and focuses on describing a step by step procedure on how to construct a "concept of fit" for a test item.

2.1. What is "Fit"

"Fit" is a difficult concept to define in one or two sentences. General concept of "Fit" has been incorporated in the core definition of ergonomics. According to Grandjean (1988), an ergonomic system is an environment that does "Fit" human capability and needs. In other words, "Fit" refers to an optimized relationship between human and the environment.

Fit in civilian clothing is broadly defined as the relationship between a garment and the body to which it conforms. Many authors consider fit a visual inspection of how something looks (Clark 1976, Farmer & Gotwals 1982, Efrat 1982). The critical part in defining fit is how to describe the relationship between the garment and the body - or the way that a garment relates to the body (Ashdown, 1991). Because our clothing is the environment immediately surrounding our bodies, we expect it to follow our body contours closely and also want it to move with us (Ashdown & Delong, 1995). We want the garment to satisfy a certain level of physical comfort as well as guarantee acceptable appearance in specific situations. In other words, fit entails physical comfort, psychological or social appropriateness, and personal preferences (Ross, 2005).

In the clothing industry, fit is generally defined based on visual appearance. However, a "well-fitted garment" has both visual and functional aspects. A well-fitted garment should *hang smoothly* and evenly on the body with *no pulls or distortion* of the fabric, *straight seams, pleasing proportions, no gaping, no constriction of the body*, and *adequate ease for movement*. Hems should be parallel to the floor unless otherwise intended, and the garment *armscyes and crotch should not constrict the body*. (Ashdown et al. 2004).

There is a long history of tailoring "rules of thumb" concerning fitting of clothing. Most of these rules are fairly well established (at least for some segments of the population.) For other items, particularly the latest high-technology protective clothing, there is little or no fitting history to provide a similar knowledge base. Therefore, for most items, the relationship between fit and anthropometry for each particular design must be explored in order to determine the optimum number, assortment, and proportioning of sizes. Robinette (1996), and Rioux and Jones (1997) debated that the fit of an item is dependent upon the individual user's anthropometry, and that for this type of gear, "Fit" is much more than just comfort and appearance. It must include safety and performance criteria as well.

For the military, the bottom line is that the fit of protective equipment directly affects mission effectiveness. Protective equipment is the gear that will be donned by aircrew. This gear includes protective respiratory equipment, helmet, gloves, boots, flight suit, G-suit, survival vest, etc. The purpose of this protective equipment ensemble is to enable and enhance military personnels' ability to accomplish their assigned missions by protecting them from chemical, biological, and radioactive hazards. When testing fit, the pass/fail fit criteria must rank safety and functional aspects over comfort and aesthetic appearance.

2.1.1. Aspects of fit

According to a 1996 Advisory Publication of the Air Standardization Coordination Committee, when testing the fit of protective equipment, there are four different types of assessments necessary for covering all aspects of fitting. They are: Dynamic, Occupation specific, Integration/Compatibility, and Static assessments.

Dynamic assessments are essentially performance tests. These tests can be generic - such as general mobility tests, while others should be grossly similar to the occupation of the wearer. This could include things such as reach envelopes, dexterity testing, climbing ladders, and simulation of crude maintenance activities.

Occupation specific assessments are similar to Dynamic assessments, but much more detailed and specific to a job requirement. For example: the need to reach parachute risers, or aircraft switches, or quickly escape from an aircraft. Both Dynamic and Occupation specific assessments are used when performing mobility tests. This ensures acceptable capability and range of movements in test items.

Integration/Compatibility assessments review whether the clothing/equipment can be used in conjunction with other clothing layers or other items of equipment. This assessment will be necessary when more than one layer of equipment is worn and will investigate compatibility among layers of gear. For example, the fit of the Anti G-suit will be assessed when donned over a flight suit or immersion suit. The following questions are examples for such an assessment:

- Is the wearability and integration of each layer within any given PFE schedule acceptable when worn in combination?
- Can the wearer be safely accommodated within the cockpit workspace without restriction to mobility or adverse interaction with the cockpit structure or controls?
- Can emergency controls be operated and can the wearer egress the cockpit without being impeded by the clothing.
- Is there still room for the mask on the face when the helmet is on?
- Is the pilot able to valsalva when the mask and helmet are on?

Integration/Compatibility assessments may occur at a separate time from the regular fit assessment because two or more items are needed to investigate compatibility among layers of gear. Also, specific environments (i.e. cockpit with an ejection seat) are required to ascertain the compatibility between the workspace and the layers of gear.

Static assessments investigate garment features by checking whether they are correctly located on the body. This is the assessment that is similar to a civilian clothing fit-test, in that appropriate amount of the extra room in the garments or the length of sleeve or pants are the basic check points. There are two critical points that should be made prior to undertaking static fit measurement. First, subject postures must be consistent. Each wearer should adopt a pre-determined posture for each of the static assessments listed. For example, have the subject stand with arms outstretched forward and horizontal, then assess the sleeve end position relative to the Ulnar Styloid (wrist bone). Or, let the subject stand with her arms on the sides, and then assess the shoulder fit relative to the Acromion point. Second, each type of assessment must be performed with the garment worn over the correct underlying layers (if appropriate). For example, when testing a G-suit, each subject must wear the appropriate underlying garments such as their flight suit or anti-exposure liners.

Out of these four assessments, the Dynamic and Occupation specific assessments are the most critical points because they have a direct impact on comfort as well as the functional aspects of the gear. Static assessment is also critical to verify whether the gear is donned in a uniform way across all military personnel. However, when it comes to evaluating multiple layers of gear, it is neither practical nor meaningful to rely on Static assessments for evaluating the garment features. This is because mobility is the bottom line for a fit evaluation of multiple layers. Evaluating garment features by palpating corresponding landmarks under multiple layers of gear (i.e. acromion location relative to Arm-hole seam) is not always possible. Thus, unless landmarks are located on the distal part of body (i.e. Lateral Malleolous or Ulnar Styloid), fit criteria should be flexible to either include or exclude Static assessments when evaluating multiple layers.

2.1.2. Characteristics of "Fit"

According to Erwin and Kinchen (1964), there are five characteristics that determine a good fit. They are ***Ease, Line, Grain, Set, and Balance.***

Ease is the "extra room" in your garment (Figure 2). The amount of ease in a clothing pattern determines how tight or loose a garment is at a given location. The amount of ease also depends on the design of the garment, current fashion, activity, personal preference (personality), fabric material, and body build.

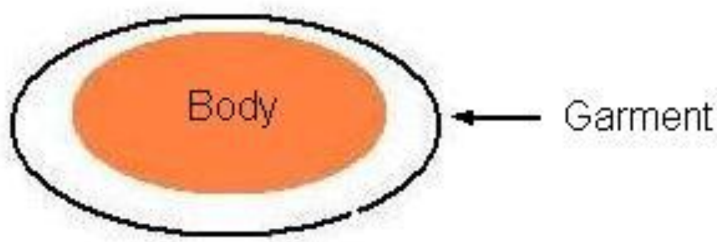


Figure 2. Theoretical cross section at clothed waist

When it comes to evaluating the amount of extra room in a test item, *Ease* is assessed as the difference between the body measurements and the measurements of the test item at a given level (Ease = garment measurement – body measurement). Thus, it is commonly expected to be a positive value, but it could also be a negative value if the garment is compressing tissue at a given level around the body. Traditionally, Ease is defined in two different ways depending on the method. They are "girth ease allowance" and "radial ease allowance". Girth ease allowance is the amount of ease measured the common way (by tuck or pinch) at testing locations. Figure 3 illustrates *Ease* as the extra amount of fabric or material at a given location – material beyond that needed to cover the skin closely but without pressure. For example, a garment with a four-inch ease around a 32-inch waist would measure 36 inches in perimeter at the waist line. Girth ease can be measured while the garment is on the person by pinching the material on the sides of the body until the garment is snug on the person. In this example (Figure 3) one inch of tuck/pinch on both

sides would equal 4 inches of overall ease at the waist because the pinched material is doubled over.

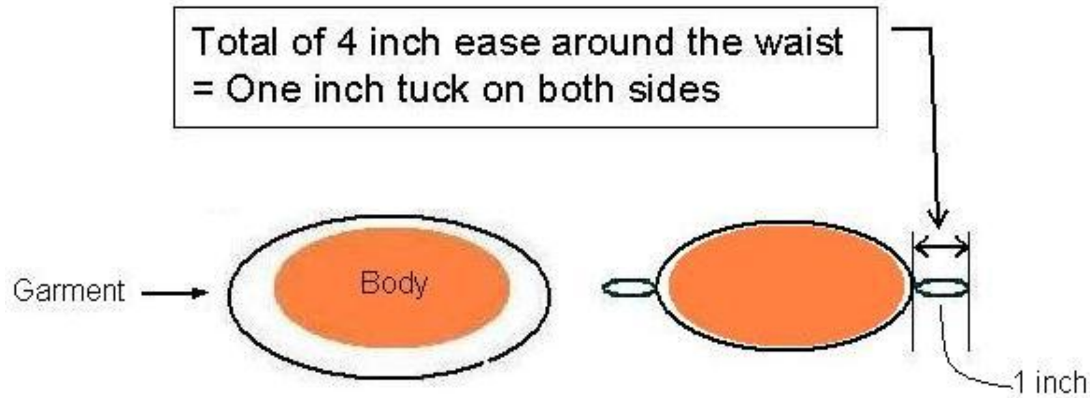


Figure 3. Estimation of girth ease around waist

Radial ease allowance is the measurement of the radial distance between a body and the test item at a specific location. For example, the distance between body and garment at the intersection of planes through the body median (Sagittal plane) and the waist level can be measured as a radial ease allowance. This method is useful to understand the ease distribution at a certain location (Wang, Newton, Ng & Zhang, 2006), and is specifically helpful to estimate the ease amount around the body when the test item is a non-fabric material such as a helmet or boot. In this manual, because most examples are flight suits, "ease" refers to girth ease allowance unless otherwise described.

Line includes all the basic silhouette seam lines, circumference seam lines, and design lines. Generally, the shoulder seam should be at or near the top of the shoulder. The shoulder seam, arm-hole and underarm seam, and the side seam of a skirt or slacks should appear continuous. The Hem line should be parallel with the floor unless otherwise intended (i.e. asymmetric cut). Pleats, darts and seams should be graceful, direct, and smooth. In a fit evaluation, this characteristic is used to inspect whether the garment is correctly located on the body by measuring the distance between the seam line and the corresponding landmark (i.e. the sleeve end is located around the Ulnar Styloid (wrist bone) or hem line is located below the Lateral Malleolous (ankle bone), etc). Refer to Section 3.4.1.B.b Line for detailed examples.

Grain is the direction (perpendicular or parallel) of yarn relative to the floor at a given location. Lengthwise grain is perpendicular to the floor at the center-front and center-back on the bodice. Crosswise yarns are parallel to the floor at the center-front and center-back.

Set addresses whether each part of a garment is attached appropriately. (eg. sleeves, front and back pieces of the torso and collar in the case of a blouse). Set is related to wrinkles on the garment. A well-fitted garment has a smooth "set" - it is free of wrinkles or unwanted creases.

Balance addresses whether the right and left sides or the front and back of garment are symmetric with each other. A skirt should hang so that it extends the same distance from the legs on both sides, right to left, and front to back unless otherwise intended.

Grain, Set and *Balance are inter-related.* If the cut is not right, the grain would be neither perpendicular nor parallel to the floor. This causes unnecessary wrinkles and asymmetry of the right and left sides of garment. Most of the time this happens during manufacturing procedures such as cutting, marking, basting (loose temporary stitches), stitching, and pressing. When performing fit-tests of protective equipment, we must assume these types of procedural problems (due to low quality manufacture) are minimal. It doesn't mean that quality problems should be ignored, but rather that they are not the main point of this manual. Prior to the fit evaluation, the size and condition of the test garments should be examined to be certain that these problems are minimal (Also, refer to Section 3.2 Test Item preparation).

Fit characteristics like *grain*, *set* or *balance* should not be given high priority in the fit-testing process for protective equipment. This process should focus almost exclusively on the "*ease*" and "*line*" fit elements because these two characteristics are the main tools in Static assessments.

2.2. Fit Criteria ("Concept of Fit")

Fit Criteria vary depending upon the item. The Fit Criteria (also referred to as a "concept of fit") are simply the way in which an item is expected or required to fit. For any fit-test, the fit criteria must enlist all functional requirements for the test item and should be translated into a consistent and *measurable* form by which fit can be evaluated and quantified. Four different aspects of fit assessments were discussed in Section 2.1.1 Aspects of fit. (Static, Dynamic, Integration/Compatibility, and Occupation specific assessments). Among these aspects, Dynamic and Occupation specific assessments are measured by mobility tests while Static assessments can be evaluated in terms of line and ease characteristics. The final fit criteria for a test item should be the composite of a testing list which allows measurable evaluation at specific body locations and shows the procedural steps to be taken. In this way, the rationale for an evaluation at a certain location can be directly explained as it relates to a functional requirement. A sample "Concept of Fit" for light weight coverall is shown in APPENDIX B. CONCEPT OF FIT.

2.2.1. Procedure for constructing "Fit criteria" (Phase 1)

There are two phases to develop Fit criteria. The first phase is a step by step procedure to list all the requirements and measurements that should be assessed during the fit test, and to translate them into a consistent and measurable form by which fit can be evaluated and quantified. Refer to Appendix B for the final product of the first phase. Second phase is to assign quantitative ranges to each requirement by which a fit evaluator can determine the pass or fail for each requirement. A preliminary test is necessary to assign numbers to the pass/fail decision. The preliminary test can be conducted in conjunction with the fit trial if all assessments are recorded as numbers along with subject preference at each assessment location during the fit trial.

The final fit criteria for a test item should be the composite form of a document that includes fit requirements with detailed instructions on the method to be used, and the pass/fail fit ranges of the requirements.

A. Observe and List the "user's functional fit requirements". Elaborate each requirement in terms of its specific action.

In general, fit requirements should seek to maximize safety and mission effectiveness. Include an accompanying list of all (within reason) activities that the potential target population would perform while wearing the testing item. These requirements will vary depending on the type of protective equipment and the mission. For fit evaluations of protective equipment (i.e. a flight coverall), test subjects should be able to perform activities such as operating hand controls, ingress or egress cockpit, and have free vision control to check six in the test item. These activities should be translated to a testable form (i.e. mobility tests) and evaluated as part of the fit assessment.

B. Categorize each requirement.

a. Breakdown each Functional Requirement based on its type. This includes static (e.g. standing measurements), dynamic (range of motion), integration and compatibility (does it work with other gear or layers of gear), and issues which may be occupation specific (reaches or escape). These are the primary criteria for testing Basic Equipment Function (Safety), Mobility, and Comfort. The aesthetic aspects of fit could also be considered, but they are usually the least important features.

b. Review each requirement and determine whether it's quantitatively measurable.

- If so, categorize them into the appropriate fit characteristics - whether it's the measurement of a line or an ease. (Use section D-G, and H)
- If not, list the requirement separately. (Use section C and H)

C. Verbally define the "well performed" condition for each fit requirement.

Describe in detail the correct task performance for each requirement in terms of body posture, equipment, and anatomical region. For example, "operating hand controls" can be simulated by hand and arm movements that show the range of hand and arm motion. Or "Ingress/Egress the cockpit" can be evaluated by leg and torso movements that show the range of leg and torso motion. These ranges of motion should not be restricted.

These requirements are measured differently. It is also important to record the subjects' assessment. Prior to fit assessment of these requirement, let subjects perform all listed mobility requirements in a minimal measuring garment. This will ensure that each subject is physically capable of performing the requirements and verify the maximum range of movement of each subject. In addition, more importantly, that will give both test subjects and evaluators the baseline data for evaluating the performance in a test item. Evaluate their performance as follows:

- When performed without any problem, score it a "PASS".
- When performed with difficulties such as: it gets tight with movement, or requires an extra effort, or an action takes significantly longer to accomplish than when performed without the test item, score it a "Marginally PASS".
- Inability to perform the task or cannot finish the task, score it a "FAIL".

D. Verbally define the "well fitted" condition for each fit requirement.

Describe in detail the well fitted condition in terms of line and ease. For example, one requirement may include a motion such as raising the legs. The thigh area as well as the crotch and hip areas could be involved. Mobility needs to be guaranteed for any such activities by assuring there is enough room (appropriate amount of ease) distributed throughout the garment where needed and that there is appropriate length for the limbs. In this way, the relevant postures, tasks, and garment or equipment areas can be associated with particular body segments.

E. Any garment location that is related to a fit requirement should be connected to a corresponding body landmark or measurement. This means defining which anatomical measure or landmark will be used to quantify the fit condition defined in sections B and D above. Relate this landmark location to a feature of the equipment. Anthropometric Landmarks are illustrated in Appendix C.

a. When evaluating a line location for garments, it should be measured from its corresponding landmark. For example, when measuring sleeve length or leg length, measure the distance from the Ulnar Styloid (wrist bone) relative to sleeve end or the distance from the Lateral Malleolous (ankle bone) to leg hem line.

b. When evaluating an ease amount for the test gear, such as the ease around the waist or chest, measure the excessive amount of fabric at the testing location, Omphalion or Thelion level, and record the values.

F. Prepare a list that includes all the fit and functional requirements for the test item.

Review the verbal description of the well-fitted condition (Refer to section D). If necessary, revise the well-fitted condition so that the sentence tells you the posture, test location and characteristics of fit.

For example, a verbal definition of "ease" amount at Hip location could be as follows:

- "Ease should be such that fit around the hips is not so loose that snagging can occur or so tight that movement is limited"

G. Converting this definition into a definition that gives test location and posture may result in the following:

- "While standing, extra fabric should exist at each side at the fullest part of the hip."

Convert the verbal descriptions of well fitted condition to an operational (measurable) definition of a well-fitted condition.

- Verbal = Hip: While standing, extra fabric should exist at each side at the fullest part of the hip.
- Measurable = X inches of ease should be available around the maximum hip location. When measuring the tuck (the ease on both sides doubled over), it should be about X/4 inches on each side (1/4 of X inches).

For each fit requirement, determine (through ***preliminary test***) the quantitative ranges for Good, Marginal, and Failing categories for the line and ease assessment (Refer to section 2.2.2 Steps to quantify each requirement (Phase 2). It's important to facilitate the recorded subjects' opinion when determining the quantitative ranges for good and marginal condition per each requirement (Refer to 4.3.1 Fit criteria (Ranges for Pass/Fail)).

H. Rank-order each "fit requirement" in terms of its importance and assign scores

Once all listed requirements are tested, an overall fit assessment on the test garments can be assigned. To do this, the assessments for each listed requirement should be converted into numbers so that the overall pass/fail decision for the test garment can be determined based on the total sum of these numbers. Subjects have to pass on all functional aspects of the fit requirement to get an overall passing fit. Other requirements such as ease or line measurements must be considered and documented, but are irrelevant if the functional aspects cannot be performed adequately. Each testing item needs to be scored differently by its type. (i.e. Each Mobility Test will be scored "5" for pass, "3" for marginally pass, and "0" for fail, but if the aspect of fit is "Aesthetic", "3" for pass, "1.5" for marginally pass, and "0" for fail). At the end of the assessment, add up all the points that the subject received. (Refer to 3.4.3.B Overall fit evaluation)

2.2.2. Steps to quantify each requirement (Phase 2)

In this phase, relate the ranges of the operational definition to the verbal descriptions of the well-fitted condition. Connecting the amount of ease or the line location to the ultimate pass/fail decision usually requires additional experimentation. This is called a preliminary test by which fit criteria can be established prior to the actual research experiments. The preliminary test can be conducted in conjunction with the fit trial if all assessments are recorded as numbers along with subject preference at each assessment location.

The measurements taken to this point do not tell you the look, comfort, or performance of the item when donned. Thus, a step to assign a value to the decision whether to pass, marginally pass, or fail (too tight/loose or too short/long) a fit is necessary. In this phase, it is recommended that fit experts or designers are involved, so that they can help develop a reasonable range of pass/fail values for the ease or line measurements. Their feedback on the fit of prototypes can result in more effective updates of the test item.

Preliminary experiments show the acceptable range from minimum to maximum allowance of ease at the fit evaluating location. During this experiment, fit evaluators should collect data that include the ease and line measurements at all required locations along with the subject assessments at each. In other words, both the fit experts' opinion and user feedback should be involved in these demonstrations. Connect the subject-rated well-fitted condition with the ease or line quantities. The results from the preliminary experiment will determine the appropriate range of ease or line amount at all listed requirements. The results

of this demonstration should be similar to the hypothetical example described below and shown in figure 4. In this example (Ease around the hip), a passing fit is between 1 and 5.5 inches of Ease. Ranking categories of fit could occur as follows:

- Good Fit: Ease amount between 2.5 and 4 inches. The best fit occurs when the measured ease amount is near the center of the range which will match the well-fitted condition based on subjects' assessments.
- Marginally Passing Fit: When the measured ease amount is within the range, but either close to the minimum amount of ease (The amount of "1 to 2.5 inches" is on the tight side) or the maximum amount of ease (The amount of "4.0 to 5.5 inches" is on the loose side).
- Fail (Unacceptable): Any measurements that are more extreme than marginal (either less than the minimum amount of ease = too tight, or greater than the maximum amount of ease = too loose)

This may be more difficult than it appears. At some point the cutoff becomes arbitrary. For the example above, an ease of 0.9 inch would be failing. However, the wearer of the garment would probably never feel the difference in that fit and one with 1.0 inch of ease. This is why recording the measurement rather than the category is important. Failing by $1/10^{th}$ of an inch (0.9 inch) is very different than having no ease at all. During data analysis this is very important information. The following figures (4a-e) show a visual comparison of "ease" allowances. One female subject tried five different sizes to make visual comparisons of the ease amount around *hip area*. She passed all the mobility tests in all sizes tested, and her rating for "fit around the hip" on each size was "Tight but wearable (32 Short)", "Good (34 Short and 36 Short)", "Loose but wearable (38 Short), and "Too loose (3-D), respectively. The waist band was not tightened.

Figure 4 (a-e). Visual inspection of ease amount at hip when standing

2.3. Chapter Summary

For protective equipment, a fit definition must consider mission effectiveness, safety and functional aspects as well as comfort and aesthetic appearance. There are four aspects of fit to assess: 1) static, 2) dynamic, 3) integration/compatibility, and 4) occupation specific assessments. During the fit-testing process for protective equipment, Dynamic and Occupation specific assessments are used when performing mobility tests, but Static assessments focus exclusively on “ease” and “line” fit elements. Along with mobility tests these two characteristics have a direct impact on body comfort as well as the more important functional aspects of the gear. When constructing a Concept of Fit, it is important that the end-users functional requirements are captured and translated into measurable entities. This is how fit-mapping results reveal the relationship between anthropometric ranges and garment dimensions. These results can then be used to suggest any pattern or size roll modifications, make tariff calculations, and determine the accommodation rate for the item.

3. FIT-MAPPING EVALUATIONS

This chapter introduces the methods for measuring the fit of test items and discusses the issues related to fit evaluation.

3.1. Fit Evaluators

There are two types of Fit Evaluators, 1) trained examiners/judges, and 2) clothing experts. Clothing experts are necessary for establishing the Concept of Fit and they have traditionally been used for performing the actual fit test. As mentioned earlier, clothing experts are believed to evaluate fit consistently and produce reliable fit quality data. However, based on a recent study, trained fit evaluators also produced reliable results. When fit-evaluation results from two separate panels were compared, one from "experts" and the other from "trained novices with detailed instruction", the differences in fit evaluation results were minimal and acceptable (Ashdown & O'Connell, 2006).

Training with detailed instruction improved judges' consistency and reliability on fit evaluation (Ashdown & O'Connell, 2006). Locating fit experts to perform fit-tests on all types of protective items is not always possible. Thus, these results are critical in that they show the impact of well developed fit criteria as well as the reliability of fit evaluations from trained non-experts.

3.2. Test Item preparation

Once a set of protective equipment items has been selected for fit-mapping, at least one of each size of the prototypes along with its size roll should be prepared for testing. The size roll shows designated body dimensions expected to fit in each garment size. It is ideal to have two of each size with a spare. Inspection must also take place for some items to ensure that they are functioning properly (e.g. When evaluating an Anti-G Suit, the suit should be checked in advance to see if the garment is properly adjusted (lacing set) and the comfort zippers can be opened/closed. This will represent how it should be worn in flight).

3.2.1. Size verification and Quality Control

It is necessary to be certain that the dimensions of each finished item match the finished dimensions and tolerances listed in its specification chart (size roll). If it is a sized item, compare them to each other to ensure the smaller size is actually smaller than the larger size. This has to be done to verify the size label and possibly identify quality control issues. If it is possible to have a pair of each size, compare the two to ensure they are identical.

3.2.2. Ease verification

If the concept-of-fit definition is ready, compare the ease amount from the fit criteria with the ease allowance in the actual garment. If the garments were correctly and consistently manufactured with the fit criteria in mind, these two ease amounts should be approximately the same.

For example, let's assume that the garment ease amount from the fit criteria requires between 6 and 10 inches of ease for a passing fit at the location of the Chest Circumference measurement (Thelion level). The size roll will show the range of Chest Circumferences that should get a passing fit in that particular size. The sum of the Chest Circumference and the

ease amount should be about the same as the garment dimension at the target location. That is, the garment dimension should be close to either the sum of the maximum Chest Circumference from the size roll *plus* the minimum ease amount necessary to get a passing fit - or - the summation of minimum body dimension and maximum acceptable ease amount.

3.3. Size Assignment

When testing the prototype, if the test subjects are pilots (or the actual users of the equipment), test their current equipment first. By doing this, each subject will have a chance to evaluate their own equipment in terms of comfort and mobility. This test will give them baseline data when evaluating the prototype test gear. In addition, the difference in pattern between current and prototype, if any, can be documented and discussed later. These differences between current and prototype equipment can be possible reasons that cause different tactile feelings and/or comfort/discomfort.

Next, based on the size roll, determine the test subjects' predicted size. Verify if the trial size fits in terms of the key dimensions (i.e. leg length and Chest Circumference for a Flight suit). If so, proceed to the fit assessment. Test up to five sizes: the original size, one size longer, one shorter, one narrower and one wider than the originally predicted size. This is not always possible or practical. If the originally predicted size is at one edge of the fit range – for example, short and tight – it does not make sense to test shorter and tighter garments. In this case, move to a longer and wider garment to start with, if that fit is acceptable, and then test the adjacent sizes. This is why the initial fit of the predicted size must be acceptable prior to starting evaluations of the adjacent sizes. The bottom line of testing multiple sizes is that the test subjects should be assessed in all sizes that he/she can physically fit in as long as the initial fit is acceptable.

By testing multiples sizes on test subjects, sizes are assessed in two ways, 1) how many different sizes have an acceptable fit for each person, and 2) what is the population (dimensions) coverage of each size. While they seem to be two separate evaluation procedures, they are simultaneously performed during a fit evaluation.

3.3.1. Assessing sizes 1: Acceptable fit range for one person

Using multiple sizes on one individual allows determination of the number of different sizes that provide a range of acceptable fit for this individual. After gathering data on many subjects, analysis will demonstrate size overlap and suggest the number of necessary sizes required to accommodate a given percentage of the user population.

3.3.2. Assessing sizes 2: Coverage of one size

By testing multiple sizes on one person, each size of garment will be tested on multiple test subjects. This allows determination of the anthropometric dimension range for each size of the garment at specific body locations (i.e. Hip Circumference Level, range of passing fit Hip Circumferences on one size) This helps establish a functional, realistic size roll for assignment of the garment and may also identify areas of the pattern that need modification.

3.4. Fit Evaluation

Once the fit criteria have been constructed, a fit evaluation should be performed following a three step procedure. This includes: 1) Mobility tests for testing the Dynamic or/and Occupation Specific assessments 2) Specific location tests for testing Static assessments. This procedure includes verifying the “Fit requirement” and assigning scores or ratings at specific locations, and 3) Overall fit assessments for determining overall pass/fail.

Measurement and evaluation of the fit criteria is the critical point of this section. Depending on the fit evaluation method, this could either be an objective measure or a subjective measure. In addition, depending on the data collection method, it could be a direct (hands-on) measure or an indirect measure such as manipulating 3-D scans with software. This section is organized by the method of data collection focusing on how to evaluate the fit requirement when it is measurable. Hence, traditional direct measures will be described first and will be followed by a section on indirect measures.

3.4.1. Direct (hands-on) measure

A. Mobility test

This is a subjective evaluation by a fit evaluator and subjects. All listed mobility tests should be evaluated by the fit evaluator (i.e. Pass, Marginally Pass, and Fail) and by the subjects (i.e. Good and comfortable, Acceptable, and Restricted). Prior to the fit assessments in a test item, these mobility tests should be conducted in a simple measuring garment (i.e. scanning garment). This will verify the maximum range of movement of each subject and ensure that each subject is physically capable of performing the mobility tests.

B. Specific Location Assessment

This is an objective evaluation by a fit evaluator, and a subjective evaluation by subjects. The investigator must measure both the ease amount at a given location and the line location from its corresponding body landmark. Typically, passing scores at a given location are recorded as good, marginal-tight/short, or marginal-loose/long. Failing scores are unacceptable-tight/short, or unacceptable – loose/long. If the fit evaluation is only being performed to discriminate whether the fit is acceptable or not, an ordinal scale like this might be enough; however, if you need to make any recommendations on how to alter the size or pattern based on the fit evaluation results, ***actual measurement values at given locations are required***. Refer to 4.3.1 Fit criteria (Ranges for Pass/Fail) for the actual usage of relating a given range of measured values to the ordinal scale.

a. Ease

Recall that ease is the amount of extra fabric in the test garment at the given location beyond that needed to fit the body closely (Refer to Section 2.1.2 Characteristics of “Fit”). If the location to be evaluated is on the torso such as the chest, waist, hip and so on, a tuck (or pinch) is measured on both sides. (In the literature, some evaluators measure ease on one side and double it. However, it cannot be guaranteed that the pinched ease amount on one side is equivalent to the other). If the location is on a limb such as upper arm, thigh, calf, and so on, measuring the tuck/pinch on one side is fine since the body tissues are not as flexible.

Ease Example: Waist circumference

A good fit may be defined as 4 to 6 inches of ease of fabric at Omphalion level.

i) Pinch (tuck) the fabric on both sides at Omphalion level (Figure 5).

ii) Measure the flattened fabric on one side and multiply by two.

iii) Repeat on the other side and sum the two numbers.

iv) The final sum is the total ease of the test size on the subject at the waist circumference level. Compare the results with the initial criteria.

Figure 5. Ease Example: Measuring Pinch at Waist circ. at Omphalion

b. Line

Recall that a line measure is the distance of a specific part of the equipment relative to a corresponding body landmark (Refer to Section 2.1.2 Characteristics of "Fit")**.** If the location to be evaluated is on the torso such as the armhole seam location relative to the Acromion, or the waist Velcro location relative to the Anterior Superior Iliac Spine, palpate the corresponding landmark through the gear. Mark the location of the palpated landmark and then measure the distance from the landmark to the specified part of the equipment. If the location is at the distal part of the limbs-such as the sleeve end relative to the Ulnar Styloid (wrist bone) or the leg hem relative to the Lateral Malleolous (ankle bone) - and the test garment covers the landmark location, fold over the hem until it is even with the landmark, and then measure the folded part of the material (Figure 6).

Line Example: Leg length

A good fit is defined as having the hem line end 2-3.5inches below the Lateral Malleolous (ankle bone):

i) If necessary, fold over the hem so that the landmark is just visible.

ii) Measure the distance between the Hem line and the ankle bone on each subject. If the hem falls above the ankle, record the value as a negative number. If below the ankle, record it as positive.

iii) Deviation within some range is appropriate. However, having the hem fall far below ankle bone (dragging the floor) is obviously too long, and if it is falling far above ankle bone it is obviously too short. For this reason, also measure the distance from the ankle landmark to the floor.

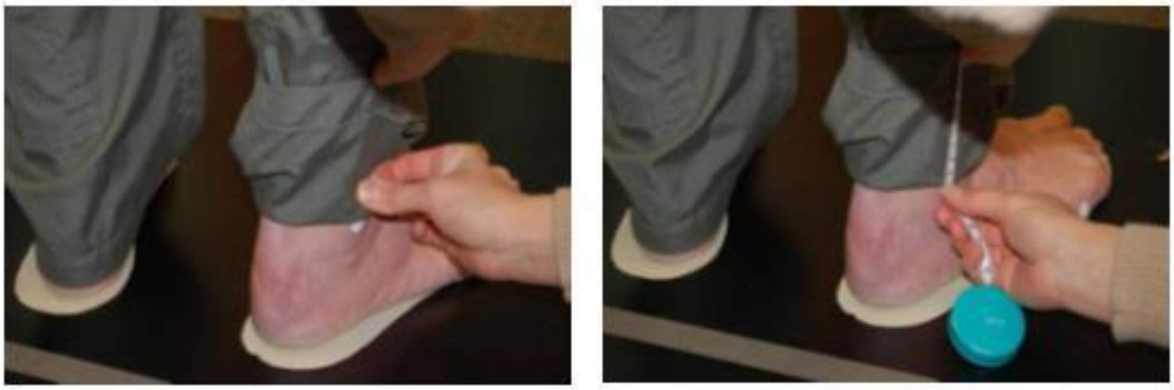


Figure 6. Leg hem from the Ankle bone

c. Subjective assessment by test subjects.

Subjects should evaluate each specific fit location and overall fit of each size that they try on. If necessary, take additional notes from the subjects about their fitting issues or preference. Ratings by subjects are valuable in that their scores are based on both visual *and* tactile information. Moreover, ratings by subjects are the guideline for determining the passing fit ranges for the fit at specific locations (Refer to Section 4.3.1.B Quantitative range). Although, it is true that the final decision regarding classifying a fit as overall passing or failing will be based heavily on the mobility tests and specific location assessments by the fitter, each subject's opinion should be seriously considered - especially when related to comfort issues. If users are not happy with the way a garment fits, they usually will change sizes without consulting an "expert". An example of subjective assessment by subjects is listed below.

1= Cannot wear it,
2=Noticeable discomfort but wearable for 2-3 hours
3=Noticeable discomfort but wearable for all day
4=OK (Minimal fit issues but ignorable)
5=Excellent (no fit issue)

C. Overall fit evaluation

When the ease and line data have been gathered, an overall score for each size for each subject can be determined. The "overall fit" evaluation is based on the mobility tests, and the specific location evaluations of line and ease, as well as an overall visual inspection. Visual cues are critical for overall fit and include (but are not limited to) wrinkles, distortions, stress folds, and the angles made by seams and edges. The fit criteria should suggest a clear guideline for overall pass and fail.

In general, there are three categories in the overall fit assessment: Fail, Pass, and Aesthetically Fail (or Marginally Pass). Subjects have to pass on all functional aspects of the fit requirement to get an overall passing fit. Other requirements such as ease or line measurements must be considered and documented, but are irrelevant if the functional aspects cannot be performed adequately. Each testing item can be scored differently by its type. For example, each Mobility Test will be scored "5" for pass, "3" for marginally pass, and "0" for fail. However, specific location test scores that are primarily "Aesthetic", can be differentiated by assigning a "3" for pass, "1.5" for marginally pass and "0" for fail. At the end of the assessment, add up all the points that the subject received, and determine the overall pass/fail as follows for example.

"PASS", if the subject passes or marginally passes all mobility tests and specific location tests, and the total score is equal to or great than 70% (or the requirement set by investigators) of the total possible score.

"Marginally PASS" or "Aesthetically FAIL", if the subject passes or marginally passes all the mobility tests and safety related specific location tests, but fails one or more of the comfort/Aesthetic related specific location tests, and the total score is equal to or great than 70% (or the requirement set by investigators) of the total possible score.

"FAIL", if the subject fails any one of the mobility tests or safety related specific location tests, or/and the total score is less than 70% (or the requirement set by investigators).

D. Rationale for objective measures and subjective measures

a. Objective measures

To be consistent across subjects, fit criteria must be developed and translated clearly into a measurable form. Evaluators then follow the procedure in a step by step manner. The critical part is to record the fit test data quantitatively (by the measured value). If the final result for the fit evaluation were only to estimate the accommodation rate (i.e. *Does a large enough percentage pass?*), just rating the fit in an ordinal scale would work. A typical five category scale (1= Fail-too tight, 2= Marginally Tight, 3=Good, 4=Marginally Loose, 5=Fail-too Loose) has the disadvantage of not describing the specific details of fit. A slight failure is indistinguishable from a major failure (also, refer to Section 2.2.2 Steps to quantify each requirement (Phase 2)).

For example, imagine an evaluation in which a number of subjects fail because the leg length of the garment is too long. If the evaluator only records that result via an ordinal scale (e.g. 5=Fail-too long), it would be difficult to modify the length of the garment so that it would fit those who failed, while not ignoring or punishing those that passed. In order for fit-mapping results to be used for pattern modification, it is important to associate the ordinal scale with a numeric fit measurement value for each subject in all tested sizes. This will be illustrated in the next chapter – data analysis.

b. Rationale, possible problems, and solutions for a Subjective Fit Evaluation

According to Leibowits and Post (1982), using the human senses as a testing instrument is a reasonable approach. The human senses can identify and process complex stimuli much more effectively than most measurement devices, especially when complex forms of pattern recognition are required. Subjective fit evaluations are one of these cases. However, while

human senses can process complex forms of patterns (and fit evaluators are usually experts at this) consistency across subjects and evaluators during an entire fit evaluation is never guaranteed. Photos (or any type of visual image) of subjects wearing the test garment can be very useful in retrospect. These photos can be revisited during analysis to assure consistency.

3.4.2. Indirect Method using a 3-D Scanner.

There are a number of studies that utilize 3-D scanners for fit-testing (Ashdown et al. 2004, Loker et al. 2005). By creating clothed body cross-sections at specific locations (i.e. the waist, abdomen, hip, and thigh) the relationship between the body and garment should be visible. (Loker et al. 2005). More of these studies are expected to come out as this technology is further developed. This section will show potential applications of 3-D scanners for fit evaluations along with their limitations. The software used for the examples in this section is InnovMetric's Polyworks.

A. Specific Location Assessment

This is an objective evaluation. Recall that the specific location assessments were done by measuring ease amounts, and by measuring the distance between garment lines and body landmarks.

The general procedure for a fit evaluation using a 3-D scanner would be 1) The subject should be scanned twice, first while wearing a minimal scanning garment, and then again in the protective equipment, 2) Align the two scan images and compare them.

a. Ease

Once the two scans are aligned, the ease amount at a given location is calculated as follows.

i) Extract cross sections from both scans at a specific body level location such as - Waist Circumference at Omphalion.

ii) Measure the surface (perimeter or cross-sectional) lengths from both scans.

iii) The ease amount at that location is the difference between the cross sectional lengths of the garment and the body.

Ease example: four cross-sections on a nude scan and a clothed scan.

Four cross-sections are obtained as shown in Figure 7. They are: chest level at Thelion, waist at Omphalion, Buttock Circumference level (most protruding point), and the maximum Hip Circumference level. All of the cross sections are measured parallel to the floor. Identical levels are used for obtaining cross-sections on both scans so that cross sections from the clothed scan can be matched with the ones from the nude scan (Figure 8). Once the cross-sections are matched, the lengths of the cross-sections at a given location are calculated for both scans (Figure 9). The ease amount around the buttocks is calculated as follows:

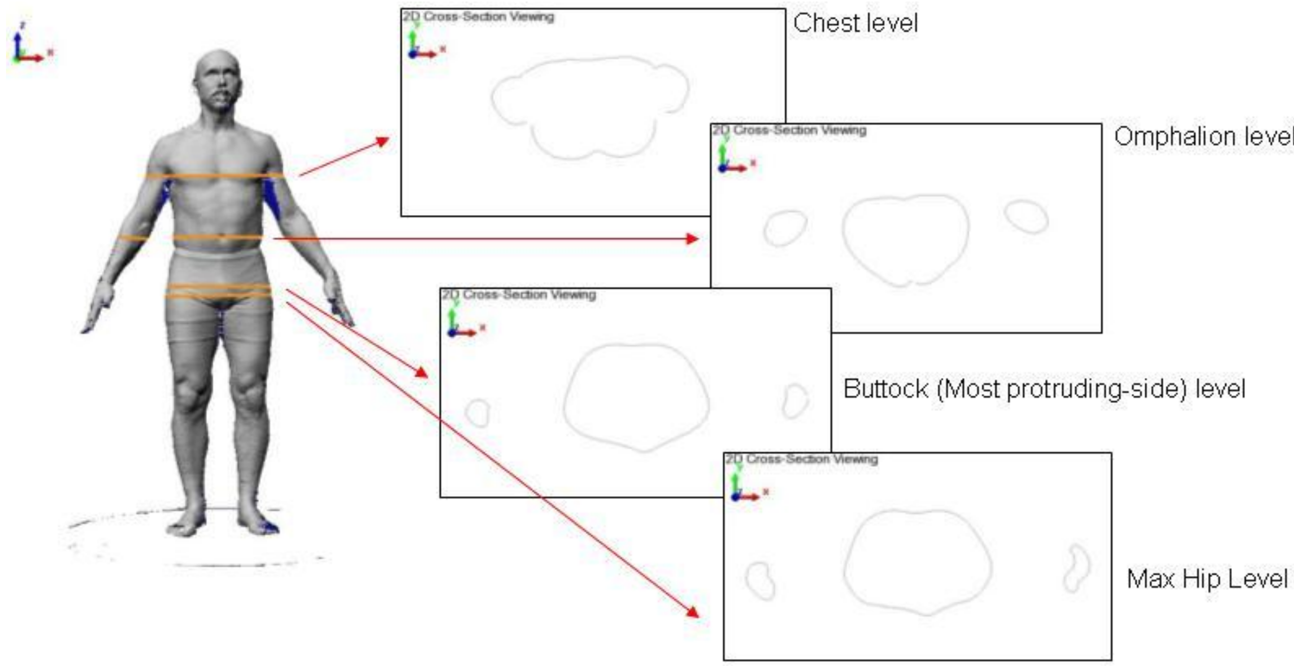


Figure 7. Cross-Sections on a nude body scan

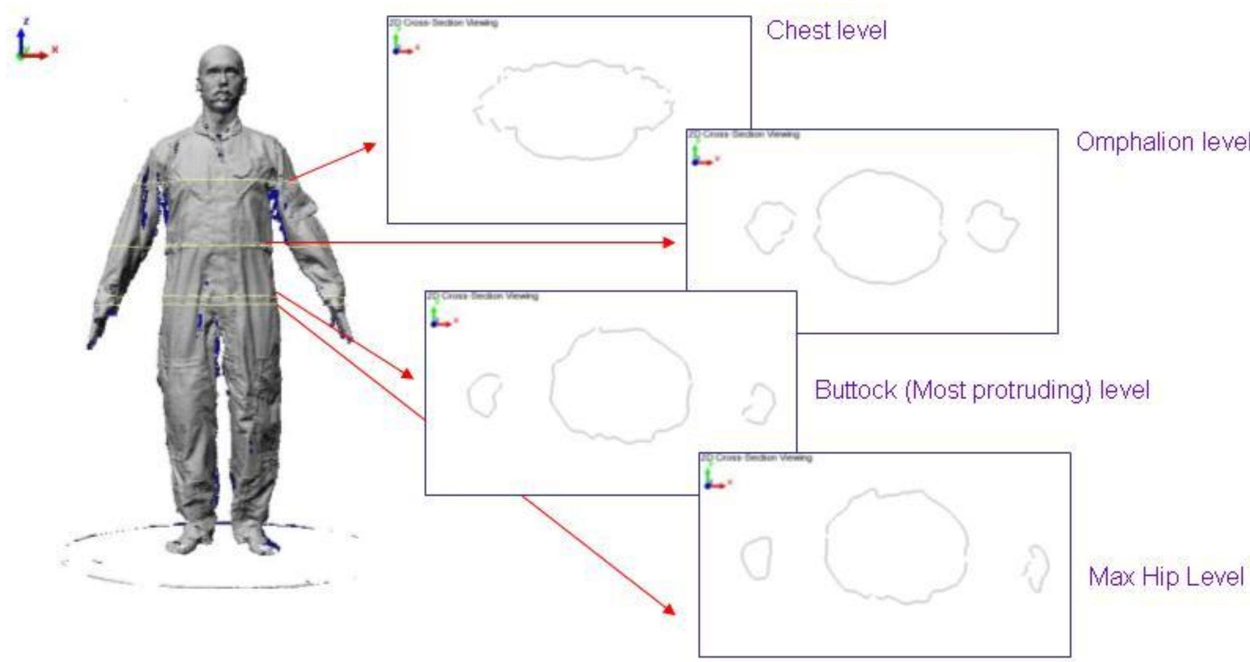


Figure 8. Cross-Sections on a clothed body scan

Ease at buttock level = garment perimeter - body perimeter
=(0.351+0.837+a+b)-(1.071)
=0.117+a+b
(Where a and b are the missing areas shown in the red circles in Figure 9.)

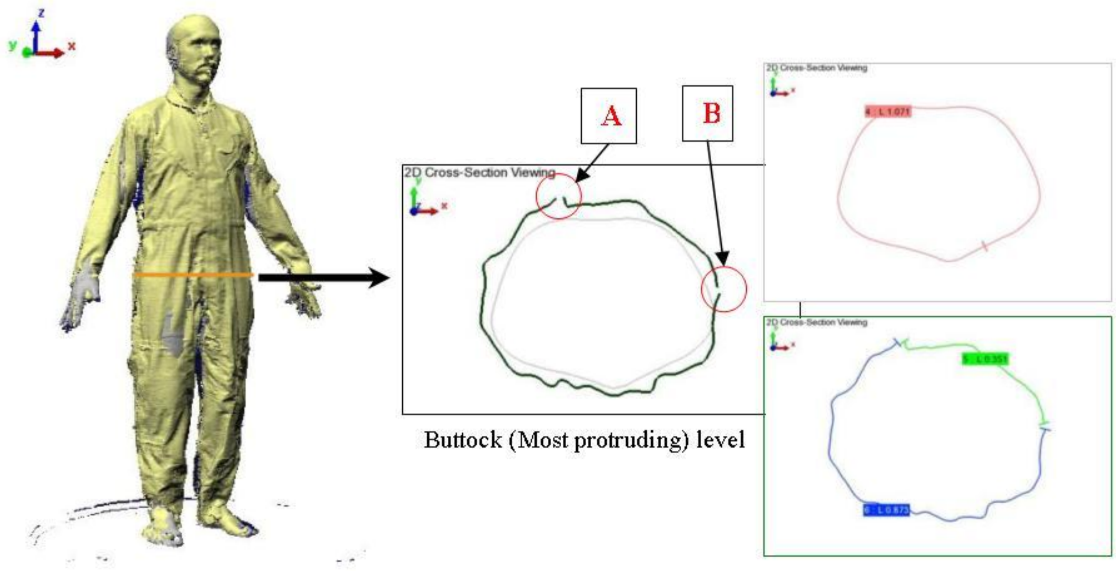


Figure 9. Ease calculations at buttock level

Ease example: A problem with scanning

If the two scans are aligned successfully, finding the cross section at the right test location should not be difficult. However, the natural characteristics of the garment such as wrinkles or folds cause problems. The cameras in the scanner cannot access any shaded (or obscured) areas of the garment. This produces holes in the data which are marked by red circles in Figure 10. These areas must be estimated if ease amounts should be calculated from the scans.

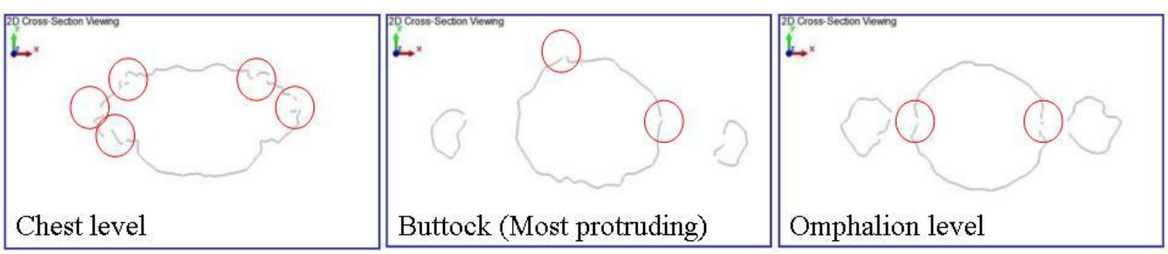


Figure 10 (a-c). Representation of shaded areas on cross sections

b. Line

Once the two scans, one from the semi-nude body and the other from test garment, are aligned, parallel planes are created.

i) Transfer the location of the seam lines (i.e. the shoulder seam, pants hem, or sleeve edge) from the clothed scan to the semi-nude scan, and the location of the landmark on the semi-nude scan to the clothed scan.

ii) Measure the distance between each line and its corresponding body landmark (i.e. the Acromion to the armhole seam, Lateral Malleolous (ankle bone) to the pants hem, etc.).

iii) The measured distance will verify whether the line is at or near the appropriate body part as described in the Concept of Fit.

Line example: Armhole seam, waist height (take up fastener), and Leg length

The created planes represent either the locations of landmarks from the semi-nude scan (Figure 11) or a specific part from the clothed scan (Figure 12). Make sure to align the two scans such that it is possible to accurately transfer the planes from the clothed scan to the semi-nude scan and vice versa (Figure 13). The distance from the planes to the landmark locations can then be measured.

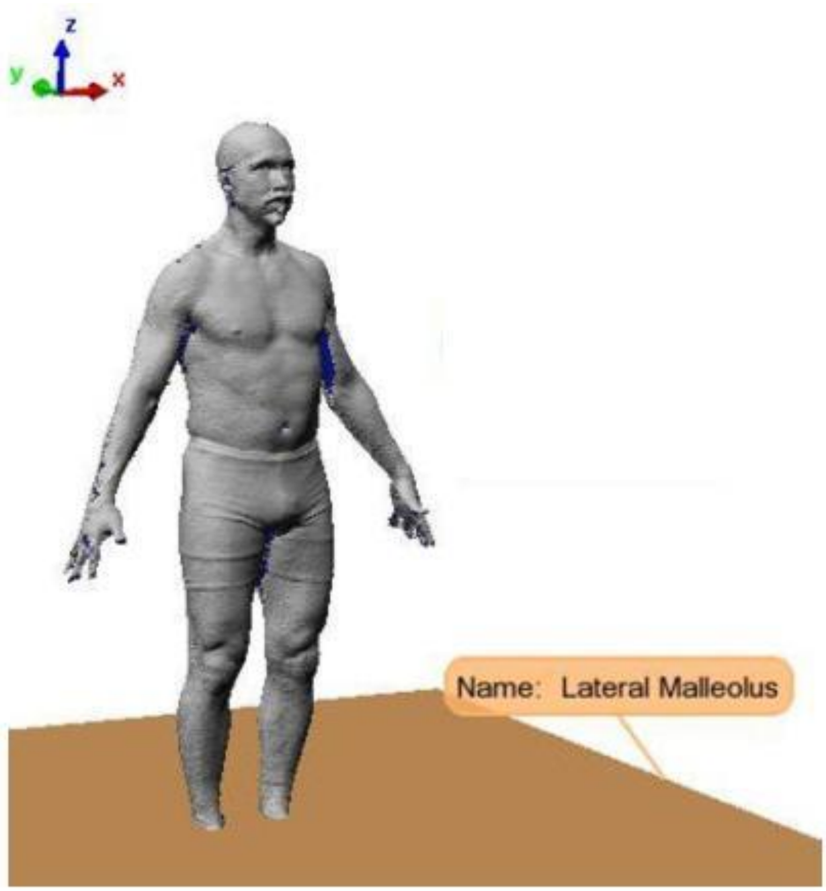


Figure 11. Cross Sectional plane on the nude scan

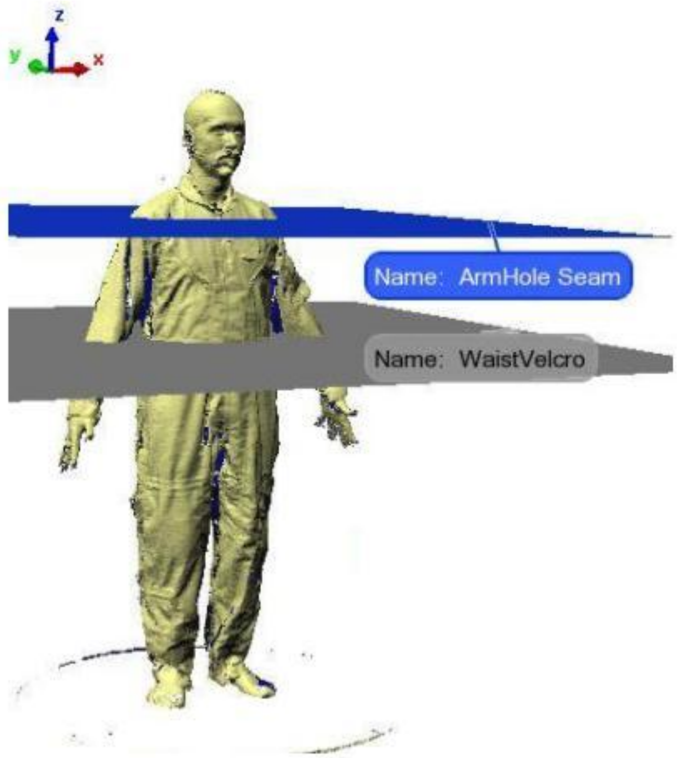


Figure 12. Cross Sectional planes on the clothed scan

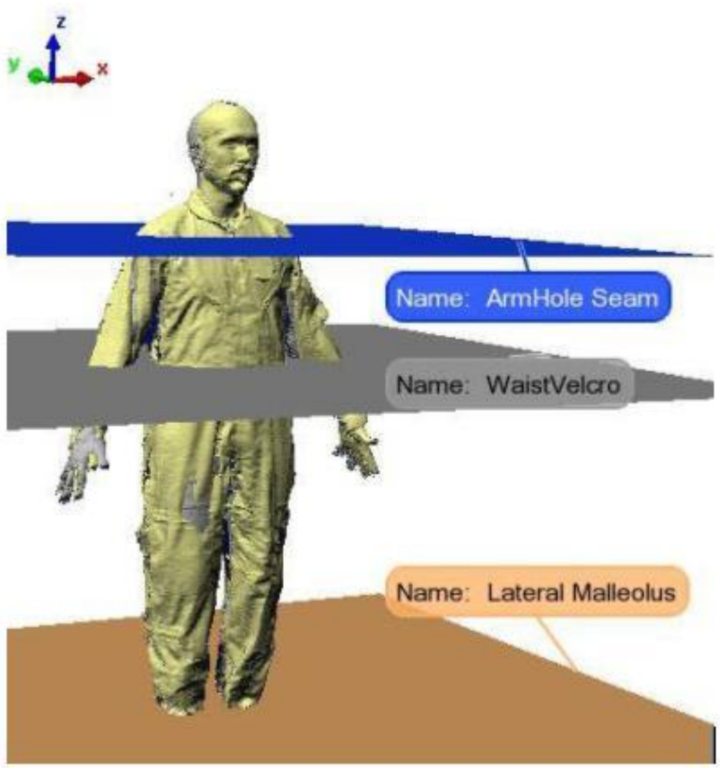


Figure 13. Planes on two aligned scans

If the line measure is similar to a surface skin-tight measure, i.e. the armhole seam location from the acromion, it is better to create a plane at the evaluating part (arm-hole seam) on the clothed scan so that the distance from the landmark to the plane can be measured on the semi-nude scan (Figure 14).

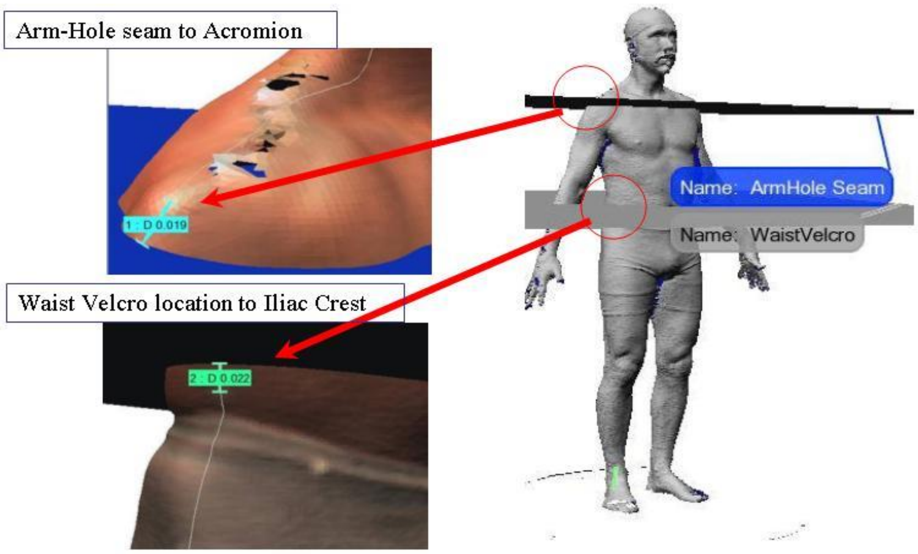


Figure 14. Line measures on nude scan

However, if it is a span measure, not a skin-tight measure, i.e. the leg hem location from the ankle bone, it is appropriate to create a plane at the evaluating landmark (Lateral Malleolous) on the nude scan so that the length from the plane to the specific part of the equipment can be a span measure (Figure 15). The measured distance will verify the location of line whether the line is at or near the appropriate body part as described in the Concept of Fit.

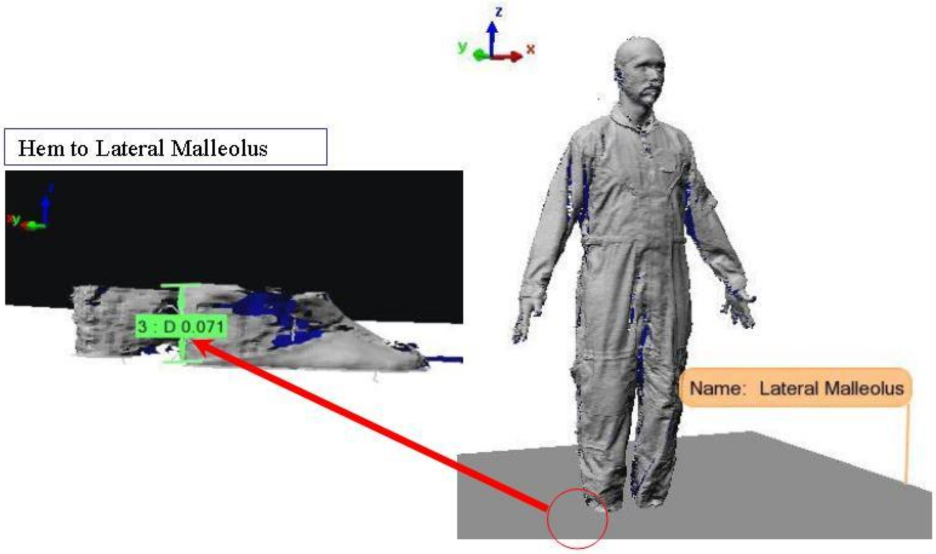


Figure 15. Line measure on clothed scan

B. Overall subjective view

a. The rationale and advantages for using a 3-D scanner

A 3-D scanned image can be rotated and enlarged to view specific areas of the body for assessing fit. This makes it easy to compare different models in the same size garment, or multiple garment sizes on one model (Figure 16). 3-D scanning of live-fit analyses creates the potential for holding virtual expert panels - where panelists can access the fit session from any geographic location (Ashdown et al., 2004).

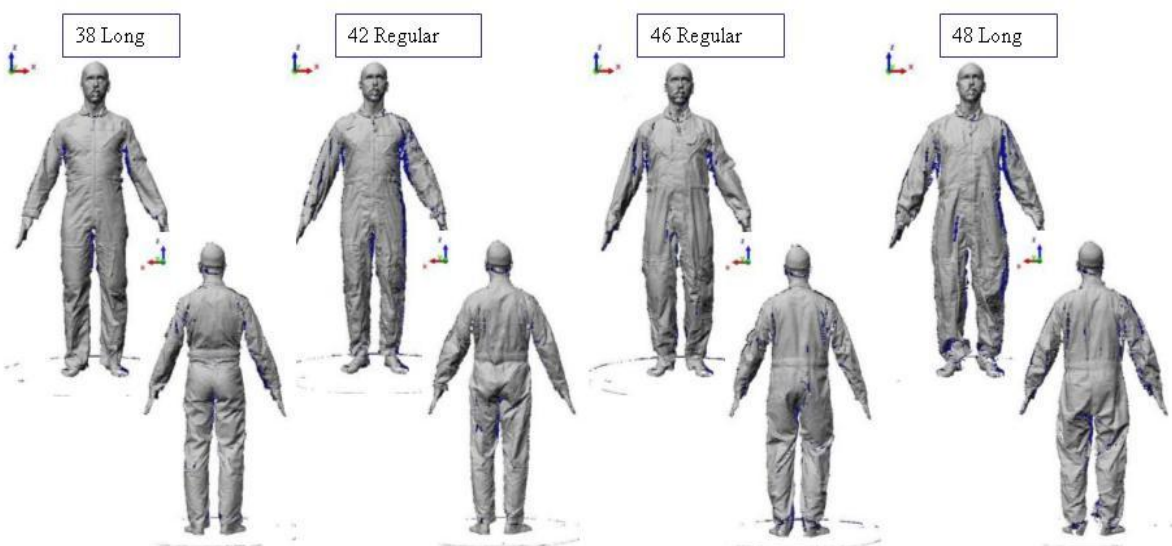


Figure 16. Four different sizes on one model

C. The advantages and disadvantages of using a 3-D Scanner for a fit evaluation

a. Overall subjective view

3-D Scanning offers the possibility of a remote fit evaluation. Captured 3-D images of live subjects in many different garment sizes can be compared to each other. In other words, 3-D scanning has a strong potential to enable a remote **visual,** comparative fit evaluation that makes subjective fit evaluations possible.

b. Specific location assessment: **Line**

Quantitative fit evaluations with a scanner are also possible. This could provide a precise method for keeping consistency across all subjects. All fit criteria would be measured and scored using this method.

c. Specific location assessment: **Ease**

This is a *major* drawback when using scanners for evaluating a garment fit.

Scanners are usually line-of-sight measuring devices. Therefore, there is no guarantee that the scanned image will always have high enough quality for quantifying fit. If the protective equipment item is *loose* on the body, the scan image could have significant shaded areas. This means <u>areas with deep wrinkles may have no data points to process</u> - because the laser cannot penetrate into the wrinkles. In other words, objective measurements, especially ease amounts, are not always measurable from scanned images because of holes in the images. However, careful registering (overlaying) of two separate scans makes it possible to assess radial ease allowances at specific locations. Using this method a 3D scanner is a good tool to assess fit for non-fabric test items such as a helmet. A helmet would not have wrinkles that cause shaded areas (no-data points) on scans (see figure 17).

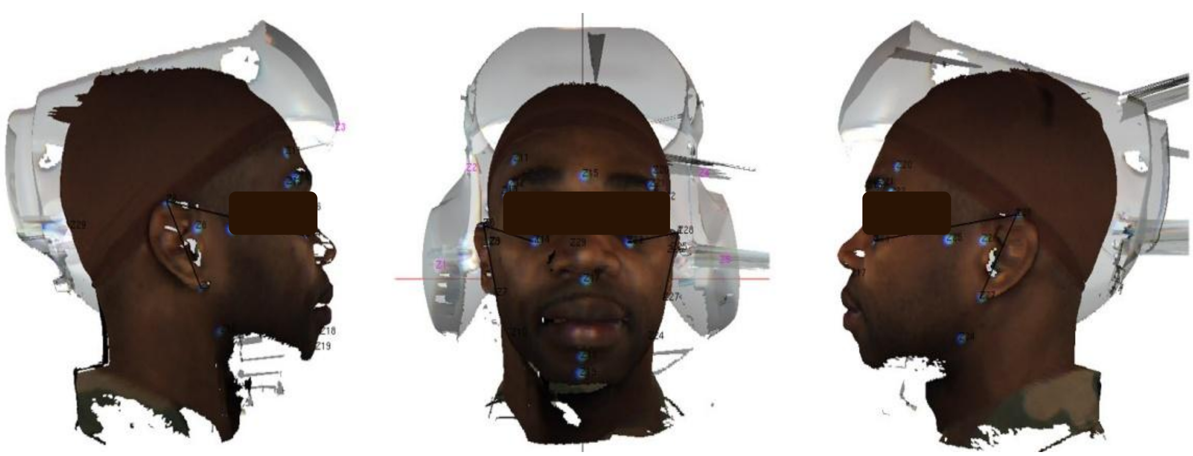


Figure 17. Aligned scans for evaluating helmet fit

3.4.3. Recommended method for Fit Evaluation: A combined approach

A. Specific location assessment

a. Ease

Due to difficulties of using current 3-D scan technology for scanning a body in loose garments, a direct (hands-on) measurement with a pinch device is recommended when assessing the fit of a garment. As mentioned earlier, keeping track of the ease measurement by value as well as on an ordinal scale is critical.

b. Line

For line measurements, both methods (3-D scanning or measuring by hand) are appropriate. Measuring by hand is relatively faster than manipulating 3-D scan to get the measurements. However, the accuracy of hand measuring might be degraded since the landmark locations are based on hand palpation through the gear and are not always visible. Using 3-D scanning could improve accuracy, but it will take additional time to manipulate the scans to get measurements. If there are many fit criteria to measure on many subjects, the time necessary to get line measurements using 3-D scans may be prohibitive.

B. Overall subjective view

Use of a device to make visual records of the fit is highly recommended. While a 3-D scan would be the best, photos from the front, side and back views will also help.

3.5. Chapter Summary

This chapter discussed issues related to fit evaluations. This included: fit evaluators, test item inspection, and the actual size assessment. Most importantly, fit evaluation methods were introduced and discussed using two different approaches, objective and subjective measures. Traditionally, fit tests were performed subjectively by experts' visual inspection. However, to quantify the outcome of a fit evaluation, it is necessary to assess fit in an objective manner by recording the outcome by actual measurement quantity. This chapter introduced and showed objective measures by demonstrating ease and line measurements. Moreover, the advantages and disadvantages of using a 3-D scanner for a fit evaluation were presented for both objective and subjective measurements. Finally, a combined approach, using traditional methods augmented with 3-D scanning was suggested.

4. **FIT-MAPPING ANALYSIS**

This chapter discusses fit mapping data analysis, and includes how to organize the fit evaluation data, as well as how to analyze, interpret, and apply the results to subsequent modifications (if necessary).

4.1. Data formatting and basic analysis

This section will introduce basic steps for analysis of fit-map data. The first step is to standardize input and format of the data. The second step is to compile frequency tables and descriptive statistics to summarize the fit data and quantify the overall degree of fit for the item. This step also includes extracting key dimensions for further analysis.

4.1.1. Variable names and labels

Long variable names are cumbersome during analysis. It is recommended they be shortened but kept with a readily available translation key for the complete names.

Data files should be saved in an interchangeable and readable format that can be opened in many statistical packages, such as STATISTICA, SPSS, SAS, S-Plus, or MATLAB. The most common and easiest way is to input raw data into an Excel or Access file.

4.1.2. Descriptive statistics

Descriptive statistics are meant to be used as summary information about the subjects and the fit test results. They include the maximum and minimum values of body dimensions that fit in each size.

If the variables are continuous, i.e. chest circumference, hip circumference, or stature, recommended outputs are the Mean, S.D., N, Min, and Max, by gender, by each size, and by their pass/fail status. If it is necessary to have a categorical variable, (such as ethnic group, Body Mass Index (BMI) group, or gender), producing frequencies, percentages, and cumulative percentages for each group would be appropriate.

4.1.3. Key dimensions

Key dimensions are the variables that will be used in the size assignment chart, and also for making 2D or 3D plots during data analysis. Since anthropometric measurements are taken along with the fit assessment, it is necessary to represent and summarize the size and shape distribution of the subject panel. Key anthropometric dimensions are selected in light of the functional requirements of the garment and with respect to the relevant measurements that will be taken in the fit mapping experiments.

A. Common variables

Key dimensions are used by people to pick out the size of garment they should wear. For that reason, they should be *common measurements* that the user should know. These are measures such as Chest Circumference, Neck Circumference and Arm Length for Dress Shirts, or Waist Circumference and Inseam Length for Pants.

B. Factor analysis

One of the methods that researchers use to determine key dimensions is “Factor Analysis”. This combines critical variables based on their intercorrelations. Table 1 highlights two of these combined groups of measurements – called *extracted factors*. Factor 1 is dominated by strong correlations with Cervicale Height, Waist Height, and Arm Length. Each of these “length type” measurements is also well correlated with each other. The second factor is defined by correlations of “circumference type” measures. They are correlated with each other – but not with the three measurements strongly correlated with Factor 1. This analysis should show variables that can be selected for use as key variables. Most of the time, the common variables are highly loaded on the factors. Notice in table 1, the measurements Cervicale Height and Chest Circumference have the highest correlation value within the highlighted group. This means they are contributing the most information about the variation in those measurements. These measures should best describe the pass/fail distribution for subjects, and therefore could be used as the key dimensions for updating the size chart. Thus, with these two key dimensions, a bivariate plot could be made. If three key measures are necessary a 3D plot would be needed etc.

Table 1. Factor analysis (Varimax rotated)

	Factor 1 Length	Factor 2 Torso size
Cervicale height	**0.95**	0.15
Waist Height, Pref	0.90	0.12
Arm Length (Spine to Wrist)	0.87	0.18
Chest Circumference	0.00	**0.90**
Hip Circumference, Maximum	0.23	**0.85**
Vertical Trunk Circumference	0.55	0.70
Expl.Var	2.83	2.09
Prp.Totl	0.47	0.35

Factor analysis is a multivariate approach. Important variable *combinations* can be identified that consider many measures simultaneously. These combinations are not obvious if only one variable at a time (univariately) is examined. Univariate tests can be misleading – causing designers to modify one part of the gear while creating another problem area elsewhere. They can also lead to inaccurate assumptions about the expected coverage of the item (Robinette, 1996, also refer to Section 4.2.1.B Theoretical Coverage, for examples).

4.2. Test sample and Population

4.2.1. User population representation

A. Sample verification

The subject pool selected for fit-mapping must represent the broad range of size and proportional variability existing in the target user population. Ideally, random sampling of the members of the end user population would be used. However, to ensure the sample is

broad enough to represent the extremes of the estimated target population, specific sizes of individuals usually need to be hand-picked and added to the subject pool. Figure 18 illustrates fit-mapping subjects overlaid on two target population samples, JSF CAESAR (Hudson, Zehner, & Robinette, 2003) and 2008 Aircrew Sizing Survey (Zehner, Fleming, Choi, & Hudson, October 2008). In this example, the pilot subjects for the fit test were randomly recruited and tested, civilian subjects were also recruited to represent extreme cases. The key dimensions used in this example are Chest Circumference and Cervicale Height. Notice that not all areas of the plot are covered completely, this is nearly impossible. However, good coverage of the distribution is essential to a good experimental design and fit-mapping results.

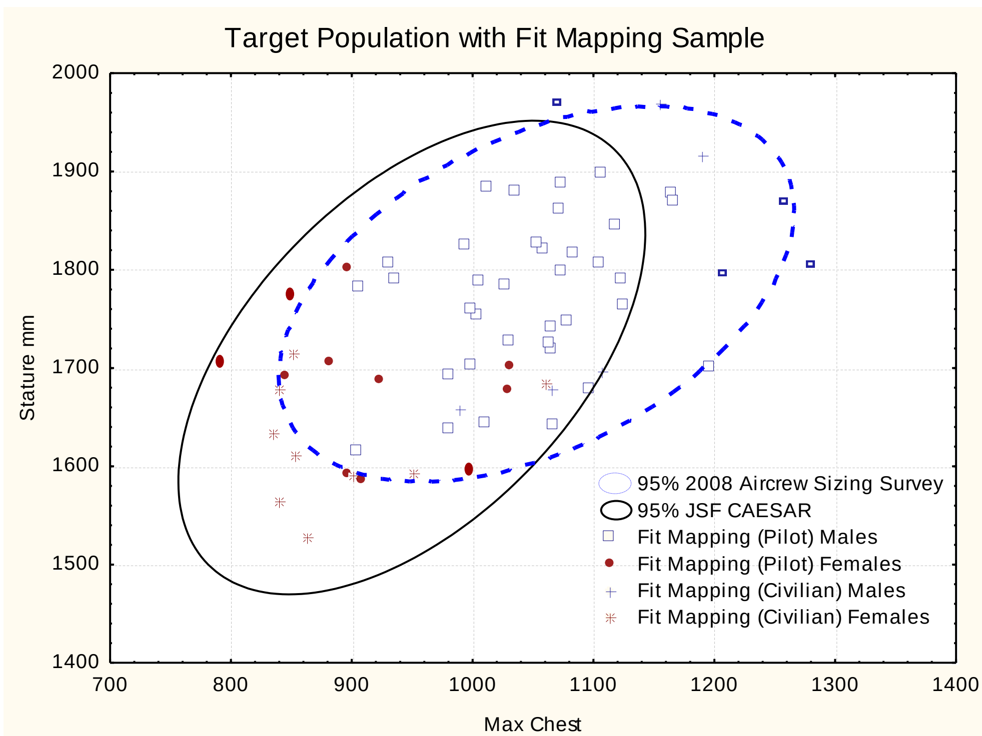


Figure 18. Fit-mapping subjects overlaid on Target Population

B. Theoretical Coverage

A *theoretical or experimental* size roll can be plotted on the representative target user population to visualize expected initial coverage of the item. Figure 19 shows the theoretical coverage of the CWU 27P length categories plotted on the target user population using "Chest Circumference" and "Crotch Height" as the key dimensions. Individuals falling inside the three boxes are assumed to be accommodated with the various chest categories. Figure 20 shows theoretical coverage of a different design of flight suit using "Chest Circumference" and "Stature" as the key dimensions.

When plotting *theoretical* coverage, care must be taken when interpreting the proportion of accommodation observed in the plots. As seen in Figure 19, there are many individuals plotted outside of the boxes. They are apparently being ignored. However, it is

not known whether the individuals outside of the boxes would fit in any of the sizes until they are tested. This is because a flight suit is a coverall that covers from the neck to below the ankle, and Crotch Height is just one segment of the overall length dimension of the human body. There are individuals who have a long torso with short limbs, and individuals that have a short torso with long limbs. Their fit would be very different in this type of garment. Actual accommodation levels will be unknown until the garment is tested. Some of those individuals initially ignored in the plot may actually be accommodated in this design. Others that are expected to fit may not.

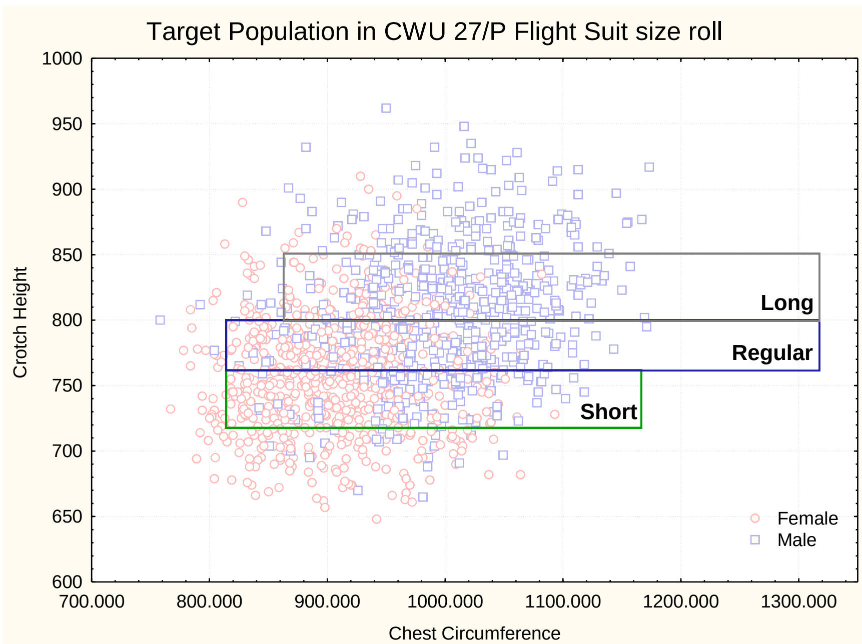


Figure 19. Theoretical coverage of CWU 27/P

On the other hand, if Stature or Cervicale Height is used as one of the key length dimensions, this includes a component of total body length, and a wider range of individuals appear to be accommodated. However, fit in the crotch area is still an issue. It is still not clear who actually fits into this garment. This is best illustrated in Figure 20. The *theoretical* accommodation rate appears to be very high because of the selection of Stature as a key dimension. However, the location of the crotch seam is still not accounted for, and there are many other measurements affecting the fit beyond the two key dimensions, Hip circumference and Arm Length for example. The *theoretical* coverage from both Figures 19 and 20 will show the expected initial accommodation based on the original size roll. However, they will probably not be the same as the final accommodation rate. This is because the actual coverage of prototype - based on the outcome of a fit mapping experiment - often shows a discrepancy from the original size roll. This is because accommodation cannot be represented perfectly with only two body dimensions. These two examples show the importance of a multivariate approach that considers many physical measurements simultaneously.

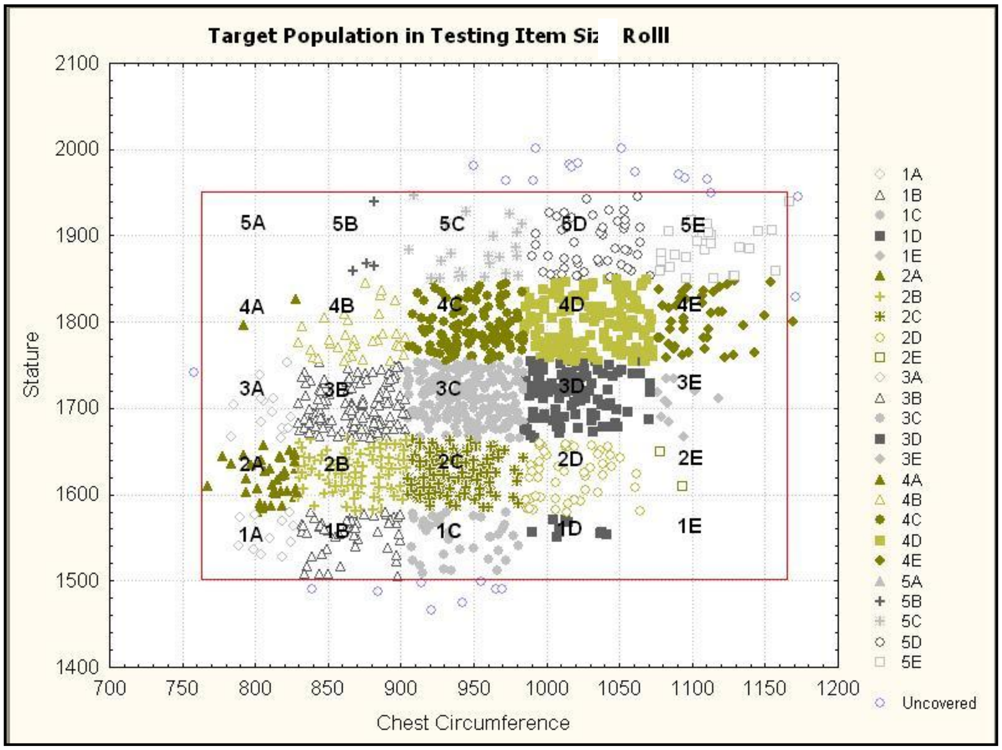


Figure 20. Theoretical coverage of prototype gear

4.2.2. Sample specification

A. Recruiting experienced subjects

Having experienced test subjects who are familiar with the item, or class of item under evaluation, is critical. A test subject who has no experience wearing a three-pound flight helmet or a leg-squeezing Anti G-Suit can rarely be objective with regard to comfort or preference. This is because they may not sense the difference between existing equipment and the new test item. In comparison, an aircrew member who may have worn such an item for several thousand flight hours will take a more realistic view of the matter, and can rapidly determine if the item is better or worse than similar items. More importantly, a pilot will be able to determine if the test item will integrate with the other items of the personal-protective clothing and equipment normally worn and whether it will allow effective function (McConville et al., 1979).

B. Non-human subjects

In some studies, dress forms or figures, or mannequins are used as substitutes for human subjects. For fit testing, dress forms or figures are useful for developing the first prototype samples for the test item. Dummy or mannequins are also frequently used for other types of testing such as high acceleration experiments that are too dangerous for human subjects.

The usefulness of these approaches is limited for testing fit. For fit testing, the quality of fit and the range of fit cannot effectively be determined until a prototype of the item is tested on actual people. Non-human subjects cannot detect discomfort. Thus, there is no feedback from non-human subjects about tactile sense or discomfort due to pressure. This could result

in an item that performs wonderfully on the model, but poorly on people. Generally, the number and variety of body sizes and shapes that are represented by mannequins or models is limited. Consequently, until these non-human models become much more like people, fit tests should use actual human test subjects (Robinette, 1996).

C. Sample size

Sample size is one of the critical features of a test that permits researchers to generalize and apply the fit map results to the entire user population. McConville et al (1979) discussed test sample size in their guidelines for fit-testing stating "…the size of the test sample depends on the nature of the item and number of sizes to be tested, on the availability of operational personnel, and on the numbers of subjects available at the extreme ends of the given body size range…". They also pointed out that the quality of the required fit is one of the most important elements affecting sample size. While some protective items must fit very closely to the body and require intense scrutiny, others do not.

In general, the more subjects you have, the more confidence you will have in the predicted accommodation rate from your fit assessment. Accordingly, there is a higher probability that the sample will represent your population well. However, funding and time limits usually force the investigator to aim for a certain level of result (i.e. accommodation rate) with the minimum number of subjects. Some recent U.S. Air Force specifications require "95% accommodation with 90% confidence". This requirement addresses two concepts: 1) the accommodation rate, and 2) the confidence level. If we look at these two concepts separately, the "95% accommodation" refers to the proportion of the population expected to be fit successfully. In other words, when testing a certain number of people at least 95% of them should pass (i.e. 95 people out of 100 or approximately 48 people out of 50 test subjects should pass). The "90% confidence" reference is the confidence value for a statistical test of proportion. In other words, when a random set of test subjects is drawn from the population repeatedly, 90% of the time the fit assessment results should show that 95% of the sample is accommodated. Thus, if we combine these two concepts, "95% accommodation with 90% confidence" would result in a 90% confidence interval for the 95% accommodation rate. A confidence interval is normally constructed from both sides from the mean or target proportion (i.e. 95% accommodation rate) as the center of the interval. However, if 95% accommodation is the minimum rate, then target accommodation rate (p) should be calculated as follows (Freund & Wilson, 2003). As seen in this formula, the target accommodation rate (p) is dependent upon the sample size (n).

$$p - z_{\alpha}\sqrt{\frac{(p)(1-p)}{n}} = .95$$

Equation 1. Formula for target accommodation rate (P)

Then, what would be the minimum sample size to satisfy this "95% accommodation with 90% confidence" requirement? Sample size can be calculated in many ways. One of the formulae that Cochran (1964:75) developed for large populations was to yield a

representative sample for proportions. The formula to calculate an appropriate sample size to satisfy “95% accommodation with 90% confidence” can be as follows (Cochran, 1963:75).

$$n_0 = \frac{Z^2 pq}{e^2}$$

Equation 2. Formula for representative sample size based on proportion

Where n_0 is the sample size, Z is the value that corresponds to the area under the normal curve which equals the desired confidence level (i.e. 90%), *e* is the desired level of precision (or allowed error level) .05, *p* is the estimated proportion of accommodation that is present in the population (95%), and *q* is 1-*p* (5%). Therefore,

$$n_0 = \frac{Z^2 pq}{e^2} = \frac{(1.645)^2(.95)(.05)}{.05^2} = 51.414 \rightarrow \text{52 people}$$

Note that the sample size can be changed depending on the equation, and the selected accommodation rate and confidence level for the equation. Based on this formula, a minimum of 52 people would be necessary to satisfy the requirement, 95% accommodation with 90% confidence. For example, if a test item has a total of 12 sizes, you could recruit roughly 4-5 subjects per each size to get this total. Or, if the test item has only 2 sizes, 26 subjects per each size would be needed. Depending on the total number of sizes of the test item, the recommended number of subjects per size could vary from 4-5 to 26. This could be problematic for two reasons. First of all, items with many sizes usually require a better quality of fit than those with a small number of sizes. However, regardless of formula, items that have a small number of sizes would have more subjects per each size than those with a large number of sizes unless there is further instruction on sample size. Twenty-six people per each size could be unnecessary for testing two sizes of an item. Secondly, when you randomly sample subjects most of them will fall near the center of the size distribution. Rarely will you get people that are suited for testing in the outlying sizes. This can create a problem. An alternative is to control the sampling and test an equal number of subjects in each size of test item. This method tests a relatively higher portion of the population in the boundary sizes and a low *relative* proportion in the central sizes. While this violates statistical assumptions of random sampling, it may be necessary to assure adequate coverage of the user population size distribution. In all, sample size should be approached with flexibility depending on: 1) the nature of the item, 2) the number of sizes to be tested, and 3) the quality of fit required - as described by McConville et al (1979).

Although it is important to determine an appropriate sample size to predict a level of accommodation, the more critical part in fit mapping experiments is how to estimate the actual accommodation rate to satisfy the requirement of “95% accommodation with 90% confidence” given the sample size. Assuming that 95% accommodation implies a lower bound of 95% and the 90% confidence is a one-tailed confidence (lower), the proportion to pass (p) based on a sample size (n) can be calculated as follow.

$$p - z_{\alpha}\sqrt{\frac{(p)(1-p)}{n}} = .95$$

Where z = 1.282 based on 90% confidence (one-sided).

Then, the accommodation rate (p) can be solved for given sample sizes based on the quadratic formula. Some example sample sizes are shown in Table 2. This also assumes that the samples well represent and cover the distribution of the target population of interest. If there are gender differences, each gender should be considered as a separate population.

Table 2. Sample size and accommodated proportion

Sample size	Accommodation rate(p)	Number of Pass	Number of Fail
25	0.983068	25	0
30	0.981516	30	0
35	0.980187	35	0
40	0.979032	40	0
45	0.978014	45	0
50	0.977824	49	1
75	0.977639	74	1
100	0.977458	98	2

4.3. Final products of data analysis

This section will discuss how fit assessment data could be analyzed, and what the corresponding final product for each process would be. They are listed as follows;

- **Fit criteria (Determine the quantitative ranges for Pass/Fail)**

Based on the fit measurements and the subject assessment ratings, the quantitative ranges for good fit, marginal fit and failing can be determined. This shows the fit of each specific location in number.

- **Accommodation rate**

This represents the total portion of the population covered by all sizes. Accommodation envelopes for each garment size will be derived.

- **Size evaluation and Modification plan**

This shows any changes to the size roll or patterns necessary to increase the accommodation percentage. If there is any difference between current and prototype protective equipment, the difference in pattern will be discussed. The revised final size roll will show the actual accommodation envelope derived for each size, and also represent any additional sizes to accommodate the target population if necessary.

- **Sizing tariff**

This shows how many of each garment size are needed to fit the aircrew population. Anthropometric data for the target population are needed to calculate the proportion of the population falling into each garment size.

4.3.1. Fit criteria (Ranges for Pass/Fail)

To determine the quantitative ranges for specific location assessments, calculate the mean of ease or line amount at each of subject assessment (Refer to Section 3.4.1.B.c. Subjective assessment by test subjects.). As shown in Figure 21, a line graph can be made to represent the line or ease amount for all subject assessment scores for each assessment location. Before constructing the quantitative range for the final fit criteria, there are two more steps: Verifying the consistency of subject assessment, and defining the lower and upper bound of "good", "marginally short/tight", and "marginally long/loose" categories.

A. Consistency in Subject assessments

It is important to check whether the subject assessments are consistent. The simplest way to verify the consistency is to compare the subject assessment score with the line and ease measurements. To statistically verify whether the subject assessments are consistent and reliable, a one-way ANOVA should be performed on each assessment. If they were consistent, the ease amount for the rating of "loose" at the chest level should be greater than that for "tight", etc. Figure 21 shows that line measures are consistent with subject assessment scale. There is, however, no difference between a score of 2 (Short but wearable for 2-3 hours) and a score of 3 (Short but wearable all day), and between score of 4 and 5, and between score of 6 and 7. In this case, it is recommended to combine the scores which do not show a difference so that the final quantitative range can be even simpler. It is also necessary to examine whether there are any gender differences in the assessments.

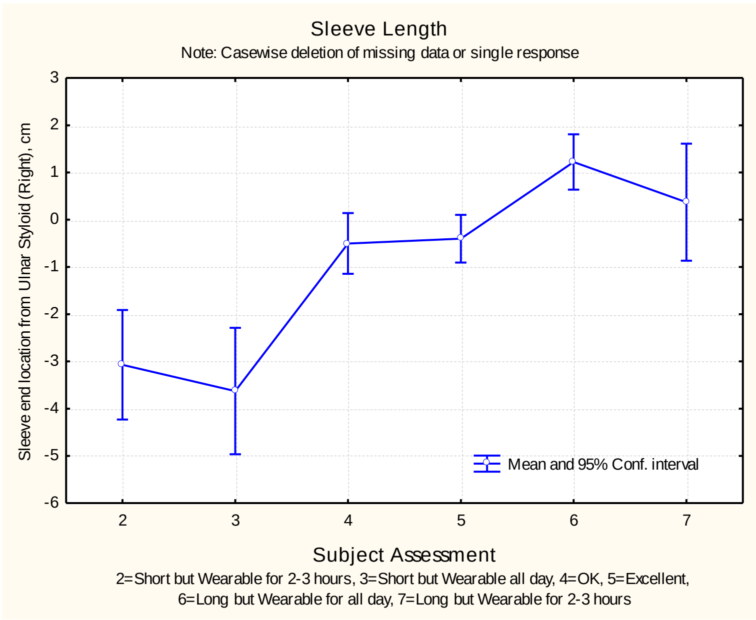


Figure 21. Sleeve Length Assessment

B. Quantitative range

It is efficient to determine the center range (range for “Good” fit) first, followed by the marginally tight/short or Long/loose fit. The “Good” range can be determined from the mean value (or the closest integer) for the line or ease measurements at subject scores of 5. Once the mean value for the center of the “Good” range is set, the lower and upper bound can be determined by the Standard Deviation value (or the closest integer).

The endpoints of the OK range can be used to determine the starting points for the marginal ranges. For example, the OK range for Sleeve length is centered at the wrist landmark, 0cm (Figure 22). Because the standard deviation is +/- 1cm, the range for an OK fit is 2cm. The upper boundary for marginally passing can be determined by adding an additional range of 2cm to the upper boundary of the OK range. The lower boundary for marginally passing can also be determined in the same way. By doing this, quantitative ranges can be constructed based on the distribution of user assessments that are rather conservative (i.e. one standard deviation up and down). In some areas of fit – for example the shoulder area – users had an overlapping range of responses. For other areas such as the hip, waist, or lengths, the responses can be very consistent.

Once the quantitative ranges are initially determined, fit experts should be involved to finalize the range based on subject assessments, fit measurements and visual cues through photos (or scans if available). Table 3 shows the finalized quantitative fit range for evaluating the line measurements. When evaluating the fit, these quantitative ranges give the standard for each location - such as whether the sleeve length is good or marginally short or long or unacceptably short or long.

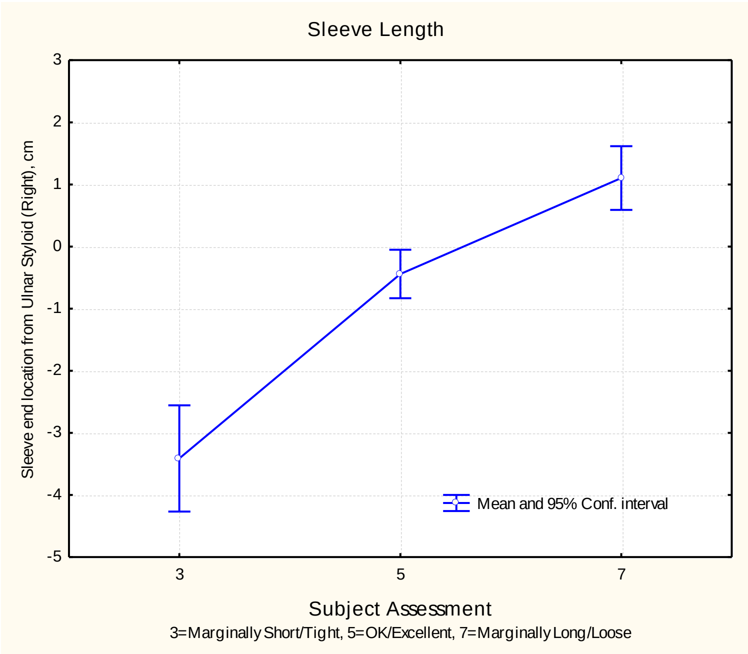


Figure 22. Sleeve Length Assessment after combining the subject assessment categories

Table 3. Example of a quantitative fit range for Line measurements

Unit : cm

	Short/High	Good	Long/Low
Sleeve	Distance from the end of sleeve to Ulnar Styloid (Right)		
	-3	-1~1	3
Neck/Collar	Distance from the end of Zipper to Suprasternale		
	-2.25	-0.75~2.25	3.75
Shoulder	Distance from the Arm-hole seam (top) to Acromion		
	-2	0~2	4
Waist Tab	Distance from the waist band to Omphalion level		
	-2.5	0.5-3.5	6.5
Leg Length	Distance from the hem to Lateral Malleolous		
	1	5~9	13

4.3.2. Accommodation Rates

Accommodation is the calculation of the percentage of a population (or sample) meeting fit-criteria for a given item. It can also be calculated for each size of a garment or item to help in determining a tariff. Test subjects of various shapes and sizes usually don more than one test item to determine the coverage of each size and to visualize how each size fits (refer to 3.3. size assignment). When calculating the overall accommodation rate, it does not matter whether one subject passes in more than one size, what matters is the percentage of total number of subjects who pass in at least one size of the item.

A. Diagram

Make a diagram that shows the overall pass/fail results of the fit evaluation. This diagram helps organize the outcome of the fit assessment. Figure 23 shows three different categories that include “Group1: Pass”, “Group2: Marginally pass (Aesthetically fail)”, “Group3: Fail”. The total accommodation rate is the percentage of number of people in group1. However, depending on the researcher’s purpose, Group2 can also be considered as a part of the accommodated portion. If necessary, each group can have subcategories such as “group1a: Pass in one or more sizes including *originally predicted size*”. Thus, this diagram can show not just the total number of subjects who passed or failed, but also shows whether people passed in their predicted size or not.

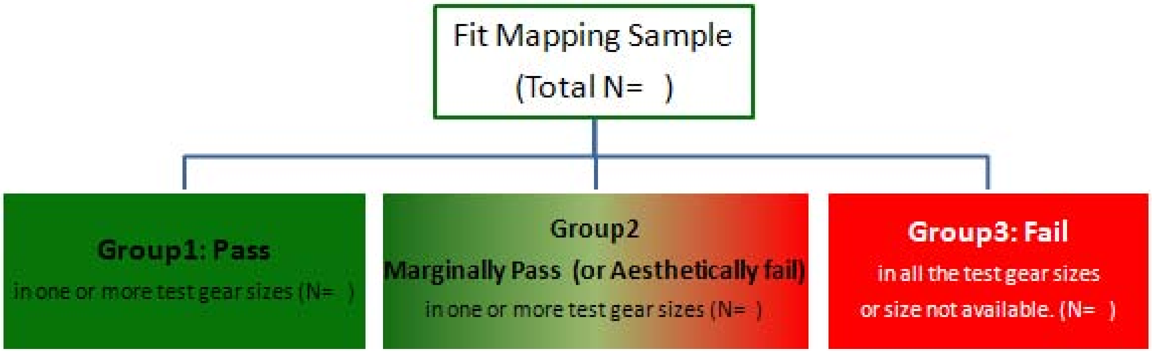


Figure 23. Fit assessment outcome diagrams

B. Organizing tables

The next step is to make an organizing table of the groups shown in Figure 23. In general, this table shows detailed information about each subject's body dimensions as well as their pass/fail status from the fit trial. Table 4 is an abbreviated version of this. It shows the gender of each subject along with their body dimensions, and also displays their pass/fail results in all test flight suits (including their predicted size). The subjects in Table 4 are the people in Group 1 from Figure 23. They passed in one or more test sizes including their originally predicted size. The last five columns show the fit results for all tested sizes of the flight suits.

This organizing table could be used to verify whether the fit evaluation was consistently assessed if additional information such as the ease and line amounts of each subject per each size tried is included. By comparing the ease amounts from two different width sizes from one person, the hands-on ease measurements could be double- checked to see if the size grading is reflected in the ease increment. In addition, by comparing the line amounts of two different length sizes on one person, leg length below the Lateral Malleolous could be a good indicator of the actual length increment between two adjacent length sizes.

Table 4. Part of an organizing table for Group 1.

Subject		Height(mm)		Circ.(mm)		Predicted	Test Flight Suits				
Number	Gender	Cerv.	Stat.	Chest	Hip	size	A	B	C	D	E
1	F	1408	1651	914	971	A	P	P	F	F	F
2	M	1434	1688	879	910	B	P	P	F	F	F
3	M	1486	1742	955	969	C	F	F	P	F	F
4	F	1470	1717	962	989	C	F	F	P	F	P
5	M	1440	1682	1037	974	D	F	F	F	P	F
6	M	1455	1694	995	1005	D	P	F	P	P	F
7	F	1546	1807	930	980	E	F	F	P	F	P
8	M	1520	1779	973	980	E	F	F	P	F	P
9	M	1536	1789	914	1017	E	F	F	P	P	P

C. Organizing Plots

The organizing table displays detailed information about each subject per each group, given an adequate sample size. However, organizing plots highlight the minimum and maximum key dimensions of people who passed in each size. Below in Figure 24, these results are displayed for one size - Test Flight Suit Size 4D. Hollow points represent people who failed the fit-test in this size. Passing evaluations are represented by dark solid points, and pastel colored solid points represent aesthetically fail. There are two shapes of filled points -square for male - and circular for female. This helps to understand gender differences. The red colored outlined area represents the initial accommodation envelope for Test Size 4D suggested by the original size roll. The green colored outlined area represents the actual accommodation envelope based on the body dimensions of test subjects who received a passing fit in this size. If there are any subjects who failed but are included inside of the accommodation envelope, the main reason for their failing should also be included. If that person is located toward the center of the envelope and failed due to one of the key dimensions, make sure the fit measurement data were recorded correctly. Since the primary purpose of this organizing plot is to provide the basis for an update of the size roll with two key dimensions, the actual coverage based on those key dimensions is critical.

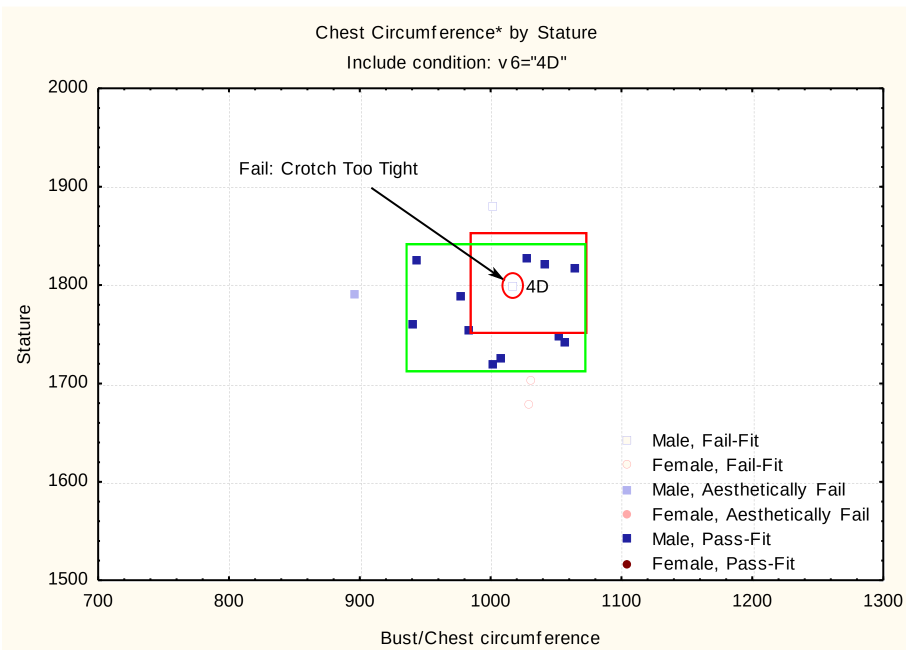


Figure 24. Organizing plot for test flight suit size 4D

D. Accommodation Envelopes

Once the organizing plots are prepared for each garment size, the maximum and minimum values of the key dimensions can be read from each plot. Make a table that represents the accommodation envelopes for these dimensions derived from the fit map (Table 5). In the example below, there appears to be a wide range of overlap in sizes. The accommodation envelopes of each size in Table 5 are based on the maximum body

dimensions that can physically fit in that size. This fit map derived accommodation envelope does not necessarily guarantee the most preferred or most comfortable range, but represents the physically possible maximum range of body dimensions for each size.

Table 5. Fit Map Derived Accommodation Envelopes

		Stature				
Chest Circumference		1	2	3	4	5
A	760-900	1500-1590	1520-1640	1590-1710		
B	820-960	1500-1620	1520-1640	1600-1720	1690-1810	
C	850-985	1500-1620	1530-1650	1620-1740	1690-1810	1755-1895
D	940-1075		1540-1660	1640-1760	1710-1830	1760-1900
E	1000-1150			1640-1760	1725-1845	1760-1900

4.3.3. Size and pattern evaluation/Modification

Size evaluation includes a process to review the fit assessment results and to extract problems and issues related to fit. Once common problems are recognized, a corresponding modification plan should be presented to show how to alter the patterns to solve the problem.

A. Review of subjective assessments

When the test subjects are pilots, it is critical to review and document their comments on the test gear (Refer to 4.2.2.A. Recruiting experienced subjects). Summarize the comments by specific locations. If there are any common problems or complaints repeatedly brought up by test subjects, make a list and revisit the pattern.

If the testing gear is an alternative or an advanced design of the existing items (i.e. flight suit, helmet, etc), it may help to compare the patterns of the current and the prototype gear. If there are any differences found in the patterns which cause the complaints, document the problem area and its potential cause. Finally, forward the documents to the designer who can review the problems and alter the pattern, if necessary.

B. Theoretical pattern modification

It is also possible to demonstrate the theoretical pattern modification and to present the resulting accommodation rate. First, determine the most common locations/reasons that cause a failing fit. An abbreviated example is shown in Figure 25. The reason that these three subjects failed in their originally predicted size (as well as the other test sizes) was tightness in the girth areas at the waist, high hip, and hip. One could ask the question - *would trying one size larger improve the fit in the hip area?* This is a very important question. Generally, when moving to a larger size, either all lengths or all girths will be larger. This may degrade the fit in areas that were previously acceptable. This is a reason why many sizes of garment are tested on each subject. When exploring many sizes of garment on one person, you should initially make sure that there are two dimensions that fit - one length and one girth (these are usually the "key dimensions"). By doing this, the size roll will be evaluated at the same time. In this example, those key dimensions are leg length and Chest Circumference. If the leg length and Chest Circumference fit are good, but the overall fit still is not passing, then look for the problem elsewhere.

From Figure 25, it is clear that when the leg length and Chest Circumference fit well, the hip area was too tight. Even when the Chest Circumference was loose, the hip area was still too tight. From these results, it is obvious that either these subjects have unusually wide hips relative to their chest girth, or the garment was designed with a narrow hip area relative to the chest, or the fit ranges in the fit criteria are not properly determined. ***Based on the assumption that the test subjects adequately represent the target population and the fit criteria are properly determined, it must be concluded that the garment pattern should be modified.*** This example used only three subjects – however, if a significant proportion of the sample has the same problem, it is obvious a modification is necessary.

To calculate the extra amount of ease needed to get passing scores for as many subjects as possible, review the minimum and maximum ease amounts from the fit criteria, and anthropometric data from the test-subjects, and calculate the additional ease that would be required to pass these subjects. Next, theoretically demonstrate that the suggested modification would increase the accommodation rate without failing previously passing subjects. ***Before concluding the modification plan, it is recommended that the theoretical modification results be re-checked to assure the pattern modifications would not fail any test subject who had previously passed.***

Subject		Height(mm)		Circ.(mm)		Predicted	Flight Suit				
Number	Gender	Cerv.	Stat.	Chest	Hip	Size	A	B	C	D	E
11	F	1432	1672	872	958	B	F	F	F	F	F
23	F	1442	1670	1005	1005	D	F	F	F	F	F
44	F	1460	1700	1010	1102	D	F	F	F	F	F

Comments - Why they failed in the originally predicted size	
Sub. 11	Leg Length (pass), chest girth(pass), High Hip (Fail-Tight)
Sub. 23	Leg Length(pass), chest girth(Pass/Loose), Waist, Hip (Fail-Tight)
Sub. 44	Leg Length (pass), chest girth(Pass/Loose), High Hip (Fail-Tight)

Recommendation

Add ~X cm to Waist, High Hip, and Hip Circumference
or ~X/4 cm to "side pinch" on both sides

Subject		Height(mm)		Circ.(mm)		Predicted	Flight Suit				
Number	Gender	Cerv.	Stat.	Chest	Hip	Size	A	B	C	D	E
11	F	1432	1672	872	958	B	F	P	F	F	F
23	F	1442	1670	1005	1005	D	P	F	P	F	F
44	F	1460	1700	1010	1102	D	F	F	P	F	F

F	New Fail after modification
P	New Pass after modification

Figure 25. Theoretical view of before and after modification

To demonstrate the effect of the modification, plot the new minimum and maximum key dimensions of people who would pass in each size. Display the outlined box on the plot to show the changes in maximum and minimum key dimensions before and after modification. If there are any changes in the number of people passing, make a note to show whether that affects the total accommodation rate (Figure 26).

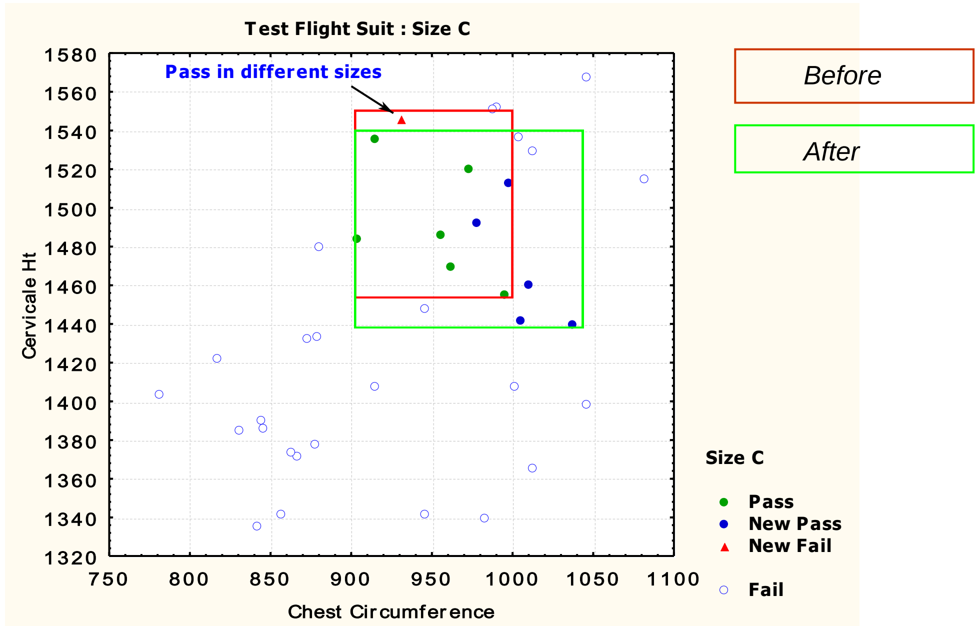


Figure 26. Accommodation plot for Size C before and after theoretical modification

The bottom line for the theoretical modification is to demonstrate whether the modification would increase the accommodation rate. However, if the accommodation rate is already close (i.e. close 90%) to the requirement for the fit mapping study (i.e. 95% accommodation) it is better to leave the modification decision to the designer.

C. Size evaluation

To evaluate the number of sizes of the test item - whether all sizes are needed or are there unnecessary sizes - a final fit map derived composite plot should be superimposed on the target population. When making the final composite plot, each test subject who got a passing fit in one or more sizes should be assigned to one size. First, all the passing sizes for that person should be compared based on their overall fit scores. The highest scored size can be selected as the best-fit size for that person. However, if there is a tie, then each fit requirement should be revisited. If one of the ties received a higher score for the mobility tests, that size should be selected as the best fit size for that person. If the overall scores and mobility scores are the same, then the first priority would be the one that has the better leg length fit, followed by chest fit. The bottom line for this process is that the subject's body dimensions should be located more toward the center of the accommodation envelope. This reduces the overlap between adjacent sizes passing people's Chest circumference and Stature are plotted. This is shown in figure 27.

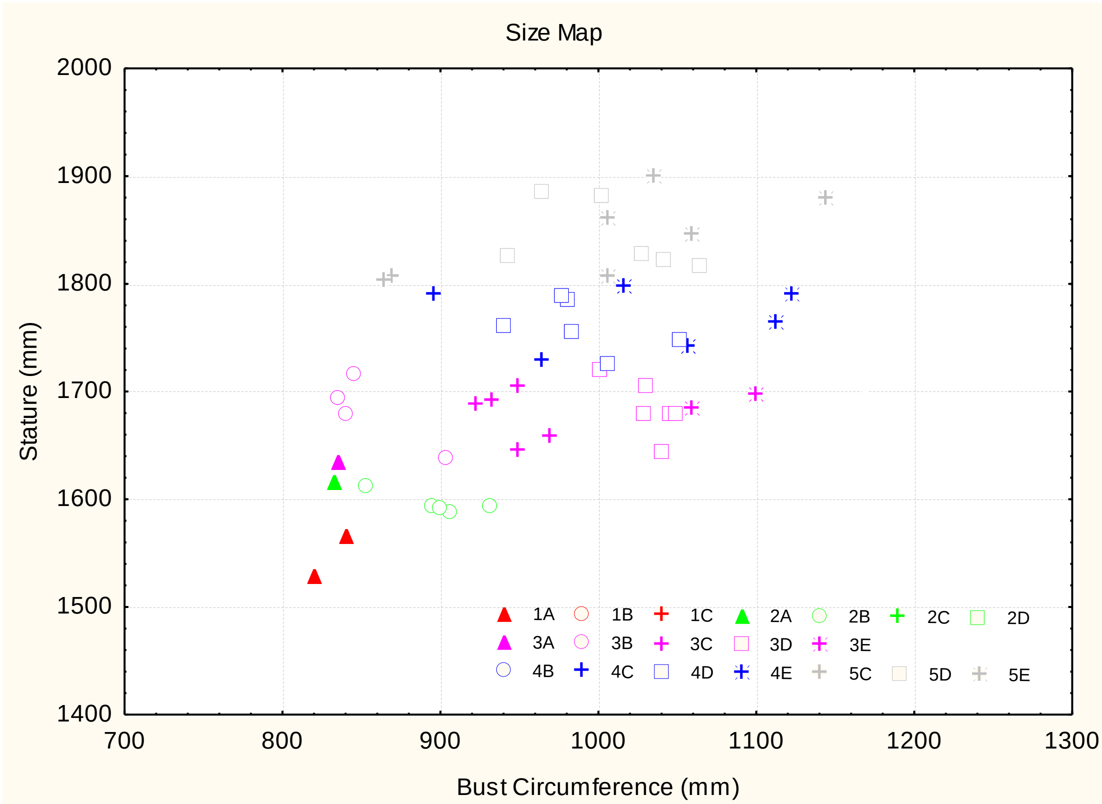


Figure 27. Composite plot of subjects in "best fit" sizes

From Figure 27, it is gleaned that each size has its own area of fit. There are five different stature classes of flight suits (1= 1500 to 1565, 2= 1565 to 1625, 3=1625 to 1725, 4=1725 to 1800, 5=1800 to 1900). Each stature class includes from one to five different chest sizes. Those five sizes fit roughly extra small, small, medium, large and extra large chest sizes. Once the best fit assignment on each subject is accomplished, their Chest Circumferences and Statures are plotted (Figure 28) over the 2008 Air Crew data (Zehner, Fleming, Choi, & Hudson, October 2008) and JSF CAESAR data (Hudson et al, 2003).

Based on the uncovered area in the background population (inside of the 95% accommodation ellipsoids), it appears there should be another stature class at the top, and an additional chest class on the right side.

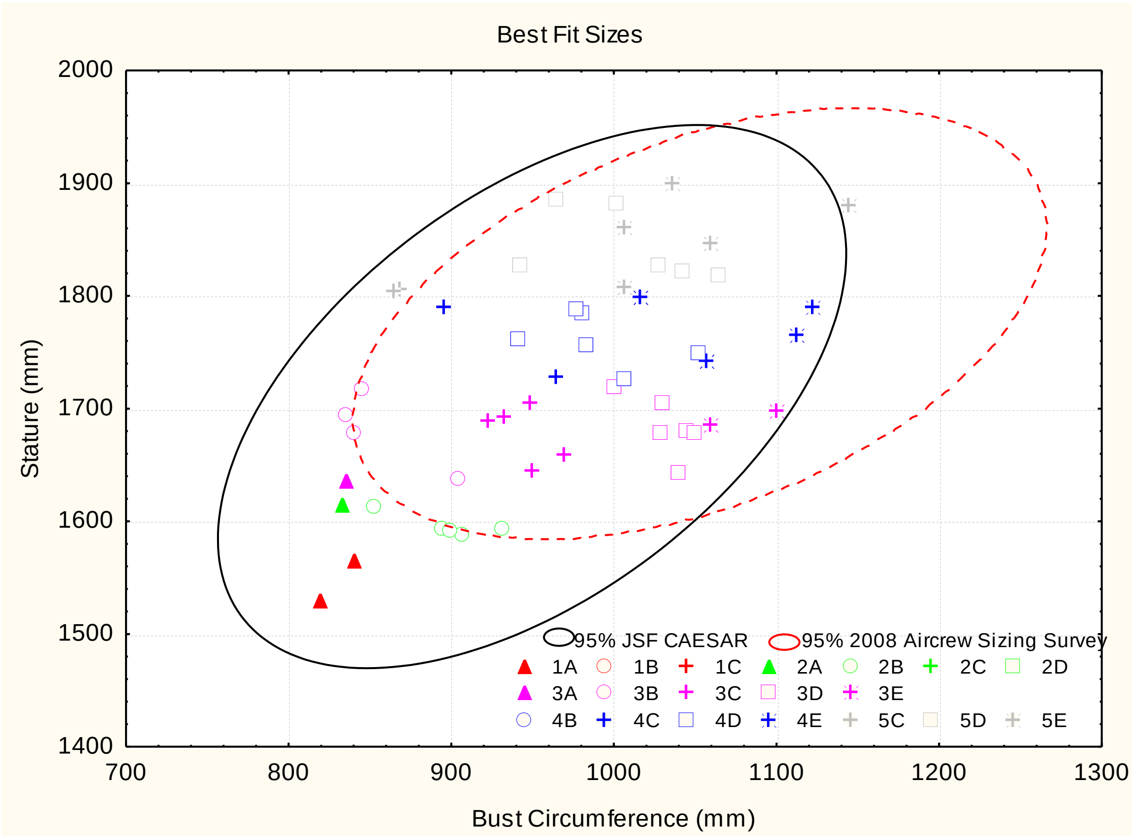


Figure 28. Size plot on 2008 Aircrew Population

Given Figures 27 and 28, a size chart (Table 6) can be developed. This size chart is also called a size roll. A size roll is a document that gives the range of body dimensions that fit in a given size of the item. Some size rolls simply list the *key dimensions* for selecting a size. For example, men's trousers might only list waist circumference and inseam length for each size. Other size rolls also include *associated dimensions* such as the hip circumference or crotch height accommodated in that pair of trousers. Finally, some size rolls also give *garment dimensions* at those locations as well. Garment dimensions include ease allowance. Table 6 shows an example of a size roll with key dimensions.

Table 6. Size chart

Stature		Chest Class						
Class	mm	A	A/B	B/C	C/D	D	D/E	E
1	up to 1565	760-840	840-860	860-940	940-980			
2	1625	760-840	840-860	860-940	940-980	980-1005	1005-1060	
3	1725	760-840	840-860	860-940	940-980	980-1005	1005-1060	1060-1150
4	1800			860-940	940-980	980-1005	1005-1060	1060-1150
5	1900				940-980	980-1005	1005-1060	1060-1150

4.3.4. Sizing Tariff

A sizing tariff determines the percentage of each size of the garment needed to be produced or procured. Once the size chart is updated, apply the minimum and maximum values of key dimensions in the size chart to the target populations. If there is more than one available target population, make a separate table for each population. Sort the population into their associated sizes and determine the number fitting into each size. Then, convert each frequency to the relative frequency (%) of the population and display the proportion of each size in a table (Table 7 and 8).

Table 7. Size Tariff for 2008 Aircrew population

	Chest Class								Row
Stature	A	A/B	B/C	C/D	D	D/E	E	Beyond E	Totals
1	0.00%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2	0.7%	0.0%	1.8%	0.7%	0.0%	0.4%	0.0%	0.0%	3.6%
3	0.4%	0.7%	4.7%	3.6%	2.2%	6.8%	1.8%	0.7%	20.9%
4	0.0%	0.4%	7.2%	5.0%	5.8%	***14.4%***	8.3%	2.5%	***43.5%***
5	0.0%	0.0%	2.2%	2.2%	1.4%	9.0%	7.9%	4.3%	27.0%
Beyond 5	0.0%	0.0%	0.0%	0.0%	1.1%	1.8%	1.8%	0.4%	5.0%
Totals	1.1%	1.1%	15.8%	11.5%	10.4%	***32.4%***	19.8%	7.9%	100.0%

Table 8. Size Tariff for JSF CAESAR

	Chest Class									
Stature	Narrow	A	A/B	B/C	C/D	D	D/E	E	Beyond E	Row Totals
Below 1	0.0%	0.1%	0.0%	0.2%	0.3%	0.0%	0.0%	0.0%	0.0%	0.6%
1	0.0%	1.2%	0.8%	1.9%	0.9%	0.1%	0.4%	0.0%	0.0%	5.4%
2	0.0%	2.5%	1.5%	7.7%	1.9%	1.0%	1.0%	0.3%	0.0%	15.9%
3	0.0%	3.7%	2.5%	***14.2%***	6.9%	2.5%	4.1%	0.8%	0.0%	***34.8%***
4	0.1%	0.8%	0.5%	6.6%	5.1%	3.2%	5.4%	2.8%	0.0%	24.5%
5	0.0%	0.1%	0.1%	2.2%	2.6%	1.7%	4.6%	3.5%	0.4%	15.2%
Beyond 5	0.0%	0.0%	0.0%	0.2%	0.4%	0.4%	1.4%	1.0%	0.2%	3.7%
All Grps	0.1%	8.4%	5.4%	***33.0%***	18.0%	8.9%	17.1%	8.4%	0.6%	100.0%

This sizing tariff table is a good indicator for the most popular sizes, unnecessary sizes, and additional sizes to include. When there is more than one target population of interest and produce a separate table per each population, compare them. If the results of size tariff are different among multiple populations, it is necessary to compare the populations and document the differences in terms of body size or/and shape.

4.4. Chapter Summary

This chapter reviewed issues related to data analysis. This included: data input, extracting key dimensions for a size roll, issues related to sampling, and the target population. The correct proportioning of an item for a given body size or type also requires knowledge about the relationship between the body and the fit of the item. For that reason, fit evaluation results should be examined relative to anthropometric survey data for the user population. In that way, size charts with the body size ranges fitting into each gear size can be produced. This chapter also presented the final products for example fit-mapping analyses - an accommodation rate, a size evaluation for pattern modification, and a size tariff and size roll. The analyses introduced are not a common statistical approach - but rather are characterized by procedural steps intended to arrive at the needed products. The steps show how to organize the fit evaluation results to calculate the portion of the population covered (Accommodation Rate), where to look to identify fit problems (Size Evaluation), how to apply the fit-mapping results to make pattern modifications, and finally, how to develop a size-roll. In addition, one of the steps allows calculation of the number of sizes needed to fit the aircrew population (Tariff).

APPENDIX A. PREPARING FOR A FIT TEST

The following content is a partial summary of an unpublished "Fit testing Handbook" report from Anthropology Research Project, Inc (now, Anthrotech, Inc) for the Air Force Research Laboratory in 1995.

Preparation for Fit Mapping should occur in five stages: 1) establishment of the fit mapping team, 2) prototyping the test plan, 3) evaluating and finalizing the test plan, 4) preparing the test facility and equipment, and 5) setting up the test site. With this approach the initial fit testing plan is refined to assure testing efficiency, effectiveness, and to work out all "bugs" prior to the start of the actual test. This preparatory phase also functions as a training phase for the data collection team. Once data collection begins, any changes in methods can affect the validity of the results, so it is important to make changes to the plan before the actual testing begins to avoid wasting time and possibly restarting the test.

A.1. Establishing team members

The fit testing team consists of individuals who will participate in the fit test throughout all phases. Determine the data collection and analysis team members early so that they may participate in the project from the beginning.

Although the roles played by individual team members that conduct the fit-test may vary depending on the type and number of items to be included in the fit-test, a team generally consists of at least four people representing all of the seven positions. They are *team leader, measurer, recorder, evaluator, fitter, briefer, and analyst*. These seven positions have specific roles and responsibilities. However, it is possible that one person will perform multiple roles on the team and also possible that many people may participate in a single role.

The Team Leader is the person responsible for making final decisions on the study and for ensuring that all aspects of the study are successfully carried out. This person should have a good understanding of the purpose of the test and the analysis methods which will be used. The main duty of this person is to coordinate the work with: 1) the sponsoring organizations(s), 2) the test site, 3) between organizations conducting the test, 4) and those providing facilities and subjects.

The Measurer is responsible for land-marking and anthropometric measuring of the subjects. To keep the consistency and accuracy, it is best if the same person is used throughout the test (at least for subjects of the same gender). Slight differences in measurement methods are usually found when different measurers are used. These variations could be enough to make analysis of the results difficult. If there are both male and female subjects in the fit test and there are measurements which might be considered sensitive if measured by someone of the opposite sex, there should be two measurers, one male and one female. In this case, it is efficient to have the measurer and recorder be of opposite sexes and trained for both positions. These two people can then trade roles, depending on the sex of the subject.

The Recorder keeps the anthropometric data records and assists the measurer, by preparing measuring instruments during measurement and checking the orientation and level of measuring tapes and equipment when necessary.

The Evaluator assesses and records the fit of the item or items. Evaluators need to be experienced or fully trained in each area of fit assessment relevant to the item. It is optimal to have a fit expert, but a novice evaluator can perform this role if properly trained to assess well developed fit criteria.

The Fitter is responsible for selecting and tracking the sizes for testing. The Fitter position may not be needed for fit studies involving a small number of items or sizes. In this case this duty can be absorbed by the evaluator.

The Briefer's responsibilities include greeting the subjects, explaining the purpose of the study, gathering demographic and biographical data, having subjects read and sign a consent form, scheduling, and tracking down subjects that fail to show up or making other such arrangements as needed during data collection. This duty can in some cases be done by the team leader.

The Analyst is the person who will analyze and interpret the results. This person should be identified early in the test plan development because the data collection methods used can greatly affect the analysis that follows.

The assignment of the initial team duties is done with the expertise of the individuals in mind. However, these duties need not be rigidly established in the beginning. It is best if there is some flexibility in duties until after the test plan is evaluated. Time constraints on some portions of the test may dictate the need for extra help in some areas and less in others.

The fit testing team will perform better given a clear understanding of the purpose of the test and the item being tested. It is recommended that the group have a kick-off meeting where the item to be tested is presented and described, and the concept of fit discussed.

A.2. Prototyping the test plan

During the prototyping phase the initial test procedures are established. This includes; determination of the data to be collected, and the selection of the experimental design. Data to be collected can be categorized into three types; 1) demographic and other background data, 2) body size and shape data (anthropometry) and 3) fit quality data. The experimental design consists of establishing all the test conditions including: subject sampling method, item assignment method, and other conditions such as other integrating equipment and environmental conditions for the test.

A.2.1. Background Data

The background data is used to describe or identify the sample. Frequently asked questions include *name, age, birth date, birth place, gender, race, occupation, education,* as well as additional questions related to the project. These data also include the information such as the test sites and dates of the testing. A sample background (demographic) data collection form is shown in Appendix D.

A.2.2. Anthropometry

Two types of anthropometric data are collected. One should be the measurements most relevant to the item being tested, and the other should be measurements that can be used to compare the sample to the target population. These are standard anthropometric variables collected during most fit tests. These standard anthropometric variables are good descriptors of the population even if they are not the most relevant to the item being measured. Also, they are usually common variables that people know about themselves. These measures can

help people find the appropriate size for clothing items if a size roll is created from the test results.

A paper data collection form for recording the data should be prepared even if the data are to be directly input into a computer. This form can be used during test planning, and after verification can be used to design the computer input program. A sample data collection form is shown in Appendix D.

A.2.3. Fit Quality Data

The fit quality data consists of at least the following: 1) An objective measure of the evaluator assessment at specific locations in all donned sizes; 2) A subjective measure of the investigators assessment of the overall fit for each donned size; 3) A final subjective measure, which is the subject's assessment of the overall fit for each size;

The paper data collection form for fit quality data should also include information about the donning sizes (i.e. size numbers), and specific comments from subjects. Refer to sections 3.3 and 3.4 for detailed information about size assignment, and fit evaluation, respectively. A sample fit quality data collection form is shown below in Appendix D.

A.3. Evaluating and finalizing the test plan

Trial fit testing is done for several reasons including: 1) to evaluate the prototype test plan using practice runs, 2) to estimate the time and sequence for scheduling of subjects and facilities and 3) to train the measurers and fitters to gather information in a standardized fashion.

A.3.1. Practice runs

A practice run prepares the team for situations and conditions which may be encountered during actual data collection. Trial fit-testing can enable the test team to discover possible flaws in the data collection process prior to actual data collection. Trial fit-testing is also a way to help familiarize the team with the fit-test set-up and the spatial layout which will be required at each test site. These practices should continue until all individuals are comfortable with their role as a briefer, measurer, recorder, fitter, or evaluator. Individual team members should use the practice runs to learn to perform their duties routinely and to interact easily with one another.

A.3.2. Schedule

Factors to be considered when a team begins scheduling the fit-test are: the length of each test cycle, rest breaks, total number of tests per day, total number of subjects per day, and total available subjects.

A test cycle is the time required for a subject or group of subjects to run through the various portions of the test. During the practice runs, carefully measure the composite test cycle - from the moment when a subject walks in to the end, when that subject walks out, as well as each portion. The anthropometric cycle may differ in length from the fit assessment cycle.

It is important to ensure that the test team is afforded a sufficient number of breaks throughout the course of any given test day. It is recommended that 10 minute breaks be provided in the schedule between each subject, with at least a half hour lunch break for every team member.

The test team should estimate how many hours a day the team can fit-test. If there are time-consuming tasks such as daily computer or equipment set-up requirements these may limit the actual data collection time to 7 hours. At the conclusion of trial fit-testing, the test team should know the "test cycle" for each portion of the test. This knowledge, combined with the estimated number of hours which the team can work daily, and the number of rest breaks needed, should allow the team to estimate the maximum number of subjects who can be fit-tested per day.

In selecting a test location, the test team should always make inquiries at the site about subject availability. If a test team is evaluating the fit of a helmet on female flyers, the test team should not only choose a test site with a large number of female flyers, but should confirm that those female flyers will be available for testing. It is not wise to assume that they will be able to get access to the female flyers at Naval Air Station XYZ simply because that Naval Air Station boasts a large population of female flyers.

If possible, it is easier for scheduling to know the total number of available subjects at the test site, first. Then, based on the test cycle measured through practice runs, break times, and lunch time, estimate the work hour per day. That will also allow estimating the maximum number of subjects who can be fit-tested per day. Then, estimate the duration of the survey of that site. Finally, check with the test site whether the survey schedule is compatible with their schedule. For example, a fit testing team plans to fit-test Item X at Air Force Base ABC. The test team has determined that it can fit-test eight subjects an hour for seven hours a day over a six-day period in order to meet the site goal of 300 subjects. (The total number of subjects scheduled should be 336. This would allow the test team to reach their goal despite the number of subjects who customarily fail to show up). The test team learns, however, the sole acceptable test site at Base ABC will be available for five days only. The test team has the option of lengthening their work day to eight hours. Although the optimum length of a work day for this particular fit-test is seven hours, the team can test eight hours a day for five days. This would allow the test team to schedule 320 subjects, which should still satisfy the goal of 300 subjects for that particular test site. The team's other option would be to search for a test site at an alternate location (Air Force Base DEF, for example). The test team would have to decide which option is more feasible taking the geographic and demographic requirements into account.

A.4.Testing facility and Equipment preparation

This section is written primarily from a field test perspective because fit-tests conducted in the field pose the greatest challenge to meeting the needs of the test team.

A.4.1. Coordination of the Test Sites

It is important to ensure adequate facilities and equipment are available at the test site upon arrival of the test team. It is strongly recommended that the team leader who also coordinates the test travels to the test site prior to testing to assess facilities. The team leader's role as a test coordinator is crucial in this context because he or she is responsible for relaying to the liaison all of the requirements for the fit-test as determined by the test team during trial fit-testing. Also, this person may be forced to improvise using available resources at the test site.

Experience has shown that even after extensive conversations, the accommodations provided may be different than those agreed to on paper or over the telephone. For example,

at one test site on a study of the Air Force Women's Uniform, the test site did not have any lighting and one of the main test areas had no electrical outlets. The availability of the lights in the room was not an item that the coordinator had anticipated mentioning. It was assumed that this was understood. The test had to be delayed while one of the members located table lamps and extension cords, which provided very minimal lighting and a very disgruntled team. If the coordinator had arranged for the facilities in person and in advance, the delay would have been avoided and other options could have been arranged. At another site, the room was the correct size, had sufficient lighting etc., but it was filled from floor to ceiling with stored equipment such that it was impossible to enter! Again, it had not occurred to the coordinator to mention that the room needed to be empty. However, in this example the coordinator had arrived a day early, was able to review several options, and an excellent facility was located.

A.4.2. General Facility Requirements

The following is a listing and description of "generic" facility requirements which have been identified in previous testing. While this may seem like a thorough list, even when it was used problems with the facilities still occurred. It is recommended that a listing such as this be used in conjunction with a pre-study visit by the coordinator to the test site. Also, arrange for a local liaison to be available during testing to inquire about subjects or help with any special problems that occur. Access to a telephone is also helpful for coordinating activities.

The measuring room should not have thick or shaggy carpeting, which will impede the measuring process. Each room will require different equipment. The measuring room needs a small table or desk, two chairs, an electrical outlet, and a wall which will accommodate a full length mirror. Tables or hangers may be required in the fitting area if several clothing sizes are being evaluated. Additional requirements include good lighting, good ventilation, appropriate heating or cooling, and low noise throughout the day. (Low noise is important not only to the investigators, but is generally appreciated by the test subjects as well.)

The measurement, fitting, and evaluation areas should be situated in three adjoining rooms, or visually divided spaces. In some instances, the fitting and evaluation areas may be combined into one room, with room dividers or curtains between the different areas. The purpose of having separate, or divided, rooms is to provide privacy when necessary, to reduce distractions during data collection, and to reduce congestion in the work area since the measuring, fitting, and evaluation sessions may run concurrently if the subjects arrive in small groups. When testing clothing, the measurement room (or area) should be the most private since the subjects may be in shorts and tank tops for females or in shorts alone for males. Easy access to male and female restrooms may also be required during clothing fit-tests if the subjects have to dress for the measurements or don a clothing item which requires them to strip to their undergarments.

The dimensions for each area are dependent on the type of item to be fit, how many items have to be fit (including fitting tools and any specialized evaluation equipment), and the number of subjects who will be in the test area at any given time. This information should be possible to estimate based upon the conditions needed for the trial fit testing.

The measurement area generally will not vary from fit-test to fit-test unless a three dimensional (3-D) surface scanner is part of the anthropometric data collection process. This is because only one subject can be measured at any given time, and because traditional

anthropometric tools do not vary greatly with the test item. Generally dimensions for the measurement area without a scanner of 10 ft, x 10ft. will be adequate. For anthropometry which includes 3-D surface, the size of the measurement area will be dictated by the size of the 3-D scanner. The size of the scanner, when it is transported, can also dictate special requirements for doorway size to enter the area.

The fitting area requires the most flexibility in terms of overall spatial requirements. It is here that subjects don and doff the test item, as well as make the necessary adjustments before moving to the evaluation area. Fitting may be as simple as donning and doffing clothing, or as complex as molding a helmet comfort liner and making adjustments to the helmet on the head and any helmet-mounted devices (audio, or-nasal or optical equipment). The fitting area may also serve as the storage area for the test equipment and must be secure for the duration of the test if it is used as after-hours storage. The size of the fitting area is dependent on the test item and is, therefore, impossible to estimate generically. The practice runs will help the team determine the size of the fitting area their test item will require.

A.5. Data collection

By the time data collection begins the procedures should be established. However, even with the best planning unforeseen things happen. This chapter is devoted to the *do's* and *don'ts* for carrying out the procedures.

A.5.1. Maintenance of Equipment and Items

Measuring equipment should be calibrated to ensure accuracy at the beginning of data collection and at other times during testing as needed. For some electronic anthropometric scanning tools, calibration may be necessary at the beginning of each day, and the data quality may also need to be visually checked briefly immediately after each scan before the subject leaves.

Anthropometric equipment that comes in contact with the body, such as tape measures or calipers, should be cleaned with alcohol after each subject. Special clothing items worn for measuring such as T-shirts and running shorts etc. will have to be cleaned after each use. It is usually best if enough of these items are available so that one load will last at least a week. Test items will also need to be cleaned regularly. Equipment such as oxygen masks can be cleaned by rubbing with a suitable cleaning solution. Arrangements will need to be made for laundering if test clothing items are reused.

Maintenance of equipment will also require periodic checking for tears, or missing fasteners, such as buttons. Repairs will have to be made on-site in many cases, depending upon the design of the experiment.

A.5.2. Acceptable and Unacceptable Procedural Changes

It is very important not to change the way data is collected in the middle of a test. If possible, it is also important not to change the roles of the measurers, and substitution of items with new ones which is not planned in the experimental design is also ill advised. All of these things introduce error into the measurement result in making the testing less powerful statistically.

There are a few changes that are acceptable if problems arise. It is usually acceptable to add data if it will not overly affect the schedule. For example, if a fit problem is identified that is not on the data sheet, a variable can be added to the sheet to record it. Make sure to

carefully record the date and subject when this additional recording began. Problems which occur only once or twice can be recorded in the comments section of the data sheet and don't need a special variable. If they occur frequently, then recording in the comments section becomes cumbersome, erratic and non-standardized. (Of course, if a good pre-test was done, the need for this should be close to zero.) Erratic and non-standardized information is potentially of no use at all.

Adding a body measurement is more difficult since it can slow down the test by increasing measuring time. It also interrupts the pace and flow of the measuring process. Furthermore, it may be difficult to add it to the direct entry software and may require later data entry. Still, if it is viewed as something that is clearly critical to the test, anthropometric measures can be added.

APPENDIX B. CONCEPT OF FIT

Mobility Tests

1. Range of hand and arm motion : Dynamic and Occupation specific
   a. Initial Posture: Standing
   b. Task: Raise arm up to the sides and overhead. When raising the arms overhead, first make a “Y” shape with the arms at the 10 and 2 o’clock positions, then make an “I” shape with both arms at 12 o’clock position, and finally bend the arms and place the hands on the top of the head.
   c. Pass/Fail
      i. Pass: Perform the task without any difficulty
      ii. Pass with difficulty: when the subject makes an extra effort, relative to that subject’s performance in the scanning garment, or the task is completed but difficulty is observed
      iii. Fail: When the task is not completed or tension around the crotch is unbearable.

Figure B1(a-d). Task descriptions for “Range of hand and arm motion”

2. Torso length (will be tested in conjunction with range of hand and arm motion)
   a. Aspects: Dynamic, Mobility and comfort
   b. Well-fitted: the crotch of the garment should make light contact with body when the arms are raised above the head with no restriction during “Range of hand and arm motion”.
   c. Assessment: Subject Response and observation
      i. Pass: When raising arms to the side, the crotch of the garment may slightly touch the body to the side of genitals. When raising the arms overhead, the crotch may be snug but should not be too restrictive to perform the task.
      ii. Marginal Pass: (Loose) when raising the arms to the side, the garment crotch does not touch the crotch to the side of genitals. When raising the arms overhead, the crotch may lightly touch and it is very easy to perform the task. (Tight) Snug fit in the crotch with minor discomfort and restriction during the raising arm motion.
      iii. Fail: (Loose) when raising the arms overhead, the garment crotch does not touch the body. (Tight) Discomfort due to tightness at crotch, and it is not possible to complete the task.

3. Range of leg movement : Dynamic, Occupation specific
   a. Initial Posture: Standing
   b. Task: First, place the right foot on a step 62cm (or 24.49 inches) above ground while the left foot is on the ground. Repeat the same task with the left foot while the right foot is on the ground.
   c. Pass/Fail:
      i. Pass: Perform the task without any difficulty
      ii. Pass with difficulty: when the subject needed an extra effort, relative to the subject's performance in scanning garments, or the task is completed but difficulty is observed
      iii. Fail: When the task cannot be completed.

Figure B2(a-b). Task descriptions for "Range of leg movement"

4. Range of torso movement : Dynamic, Occupation specific
   a. Initial Posture: Seated
   b. Task: Loosen and fasten the bootlaces while seated. Do this task on both legs - one leg at a time.
   c. Pass/Fail:
      i. Pass: Performs the task without any difficulty
      ii. Pass with difficulty: when the subject needs to make an extra effort, relative to that subject's performance in scanning garments or the task is completed but difficulty is observed
      iii. Fail: When the task cannot be completed or there is excessive tension around the abdomen area.

Figure B3. Task descriptions for “Range of torso movement”

5. Range of head movement (Rotating): Dynamic, Occupation specific
   a. Initial Posture: Seated
   b. Task: While seated, look to the rear direction with both hands clasped behind the head, and read the letters on the wall. The distance between subject seated location and the wall is TBD meters. Letter size is TBD
   c. Pass/Fail:
      i. Pass: Perform the task without any difficulty
      ii. Pass with difficulty: when the subject needed an extra effort, relative to the subject’s performance in scanning garments, or the task is completed but difficulty is observed
      iii. Fail: When the task cannot be completed.

Figure B4(a-b). Task descriptions for “Range of head movement”

Specific Location Test

A ***preliminary test*** is necessary to assign numbers to the pass/fail decision. The preliminary test can be conducted in conjunction with the fit trial if all assessments are recorded as numbers along with subject preference at each assess location during the fit trial.

A. Line measure

1. Neck and collar

a. Aspects of fit: Static, mobility and comfort
b. Subject posture: Standing
c. Well-fitted: Should be easy to zip up. The zipper should end near Suprasternale.
d. Line measure: The distance between the end of the zipper and Suprasternale.

Figure B5. Fit evaluation description for "Neck and Collar"

2. Shoulder location

a. Aspects: Static, comfort and Aesthetic
b. Subject posture: Standing
c. Well-fitted: The upper arm-hole seam should fall around the Acromion point.
d. Line Measure: Distance between the end of shoulder (Arm-hole) seam and the Acromion.

Figure B6. Fit evaluation description for "Shoulder location"

3. Waist height

a. Aspects: Static, aesthetic,
b. Subject posture: Standing
c. Well-fitted: At or around the Omphalion point.
d. Line measure: The distance between the center of the waist band and Omphalion

Figure B7. Fit evaluation description for "Waist Height"

4. Sleeve length

a. Aspects: Static, Safety
b. Subject posture: Seated, arms straight between the legs, with hands together.
c. Well-fitted: The edge of the sleeve should end at or around the wrist bone.
d. Line Measure: Distance between the end of sleeve and the Ulnar Styloid point.

Figure B8. Fit evaluation description for "Sleeve Length"

5. Leg length

a. Aspects: Static, Comfort and Aesthetic
b. Subject posture: Standing
c. Well-fitted: Between the ankle bone (Lateral Malleolous) and floor. Not above the ankle bone and not dragging the floor.
d. Line Measure: Distance between the hem and the Lateral Malleolous.

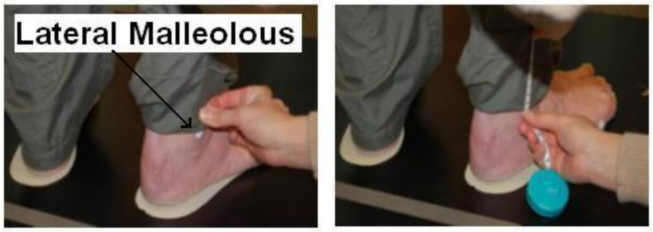


Figure B9. Fit evaluation description for "Leg Length"

B. Ease measures

1. Armscye

a. Aspects: Static, Comfort,
b. Subject posture: Standing with the arms raised and together in a Genie position
c. Well-fitted: When the arms are raised slightly, the armhole should not be too high or not too low
d. Ease measure: Pinch extra fabric at the bottom of axilla.

Figure B10. Fit evaluation description for "Armscye"

2. Chest area

a. Aspects: Static, Comfort,
b. Subject Posture: Standing with the arms raised slightly to the side
c. Well-fitted: While standing, there should be some extra fabric at each side at the fullest part of the chest.
d. Ease measure: Pinch extra fabric at both sides at the chest level.

Figure B11. Fit evaluation description for "Chest"

3. Waist area

a. Aspects: Static, Comfort, aesthetic
b. Subject posture: Standing with the arms crossed at the chest
c. Well-fitted: While standing, there should be some extra fabric at each side at Omphalion.
d. Ease measure: Pinch extra fabric at both sides at the Omphalion level, when subjects raise their arms slightly upward.

Figure B12. Fit evaluation description for "Waist"

4. **Hip area**

a. Aspects: Static, comfort and aesthetic
b. Subject posture: Standing with arms crossed at the chest
c. Well-fitted: While standing, there should be some extra fabric at each side at the fullest part of the hip
d. Ease measure: Pinch extra fabric at both sides at the maximum hip level, when subjects raise their arms slightly to the side

Figure B13. Fit evaluation description for "Hip"

5. **Crotch length 2**

a. Aspects: Static, Mobility and comfort
b. Subject posture: Standing with arms crossed at the chest
c. Well-fitted: While standing, there should be some extra fabric at center back
d. Ease measure: Vertical pinch extra fabric at the center back, when subjects are standing.

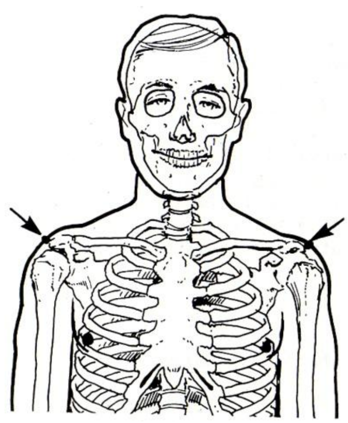
Figure B14. Fit evaluation description for "Crotch Length2"

APPENDIX C. BODY LANDMARKS

ANATOMICAL LANDMARK DESCRIPTIONS

Landmark Name: ACROMION
ISO Definition No. 2.2.1
CAESAR Name: Acromion

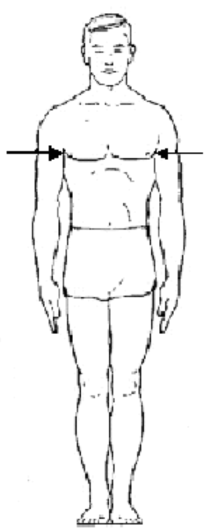
Description: Most lateral point of the lateral edge of the spine of the scapula.



Landmark Name: Axilla Point, Anterior; Left and Right
ISO Definition No. N/A
CAESAR Name: AXILLA POINT, ANTERIOR; LEFT AND RIGHT

Description: Lowest point on the anterior axillary fold (armpit).

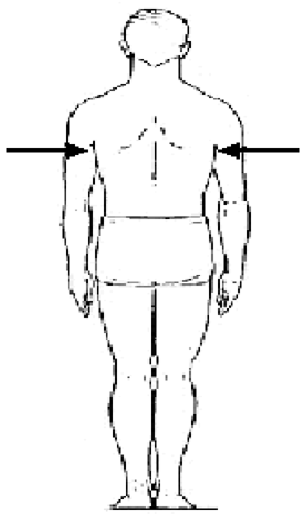
Note: *For scans, one adhesive dot is placed on the arm and one on the torso at the level of the lowest point on the axillary fold.*



Landmark Name: Axilla Point, Posterior; Left and Right
ISO Definition No. N/A
CAESAR Name: AXILLA POINT, POSTERIOR; LEFT AND RIGHT

Description: Lowest point on the posterior axillary fold (armpit).

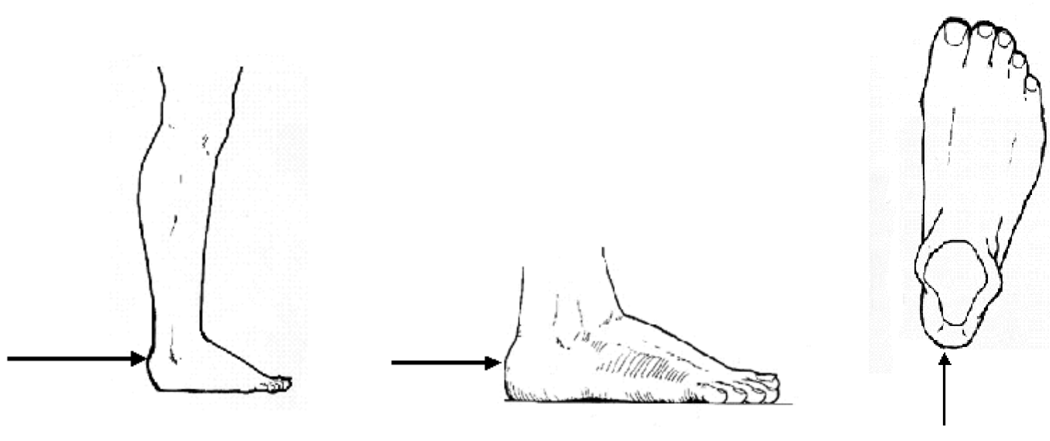
Note: *For scans, one adhesive dot is placed on the arm and one on the torso at the level of the lowest point on the axillary fold.*



Landmark Name: Calcaneus, Posterior; Left and Right
ISO Definition No. N/A
CAESAR Name: CALCANEUS, POSTERIOR; LEFT AND RIGHT

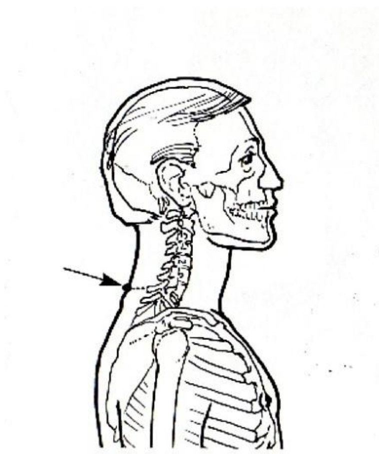
Description: Most prominent posterior point of the heel.

Note: *The most prominent point on the heel may be on the tissue rather than on the Calcaneus bone.*



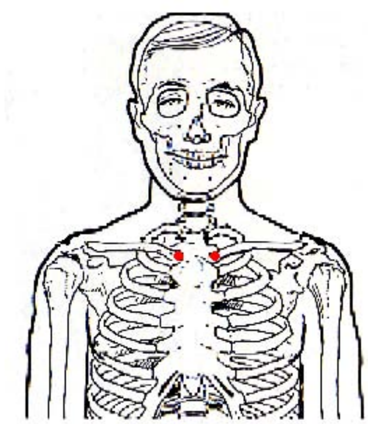
Landmark Name: CERVICALE
ISO Definition No. 2.2.5
CAESAR Name: Cervicale

Description: Prominent bone at the base of the back of the neck (spinous process of the seventh cervical vertebra).



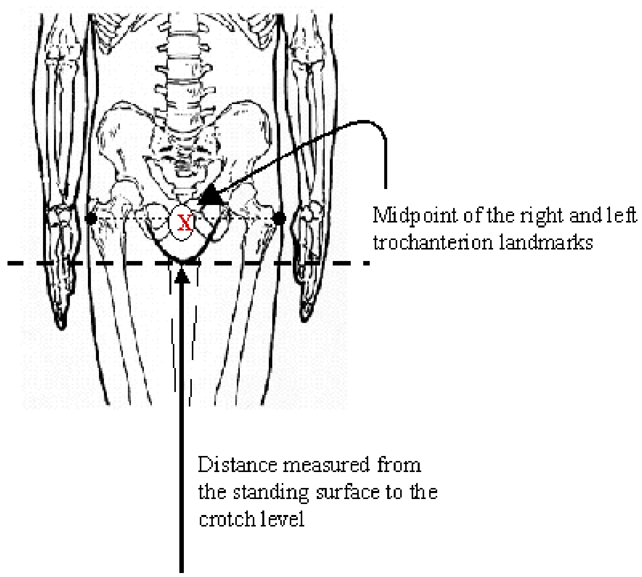
Landmark Name: Clavicale, Left and Right
ISO Definition No. N/A
CAESAR Name: CLAVICALE, LEFT AND RIGHT

Description: Most prominent point of the superior aspect of the medial end of the clavicale at the sterno-clavicular junction.



Landmark Name: Crotch
ISO Definition No. N/A
CAESAR Name: CROTCH

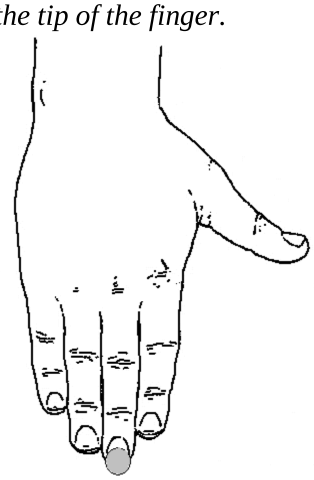
Description: Point calculated midway between the right and left trochanterion landmarks at the level of Crotch Height as measured with the anthropometer.



Landmark Name: Dactylion, Left and Right
ISO Definition No. N/A
CAESAR Name: DACTYLION, LEFT AND RIGHT

Description: Tip of the middle finger.

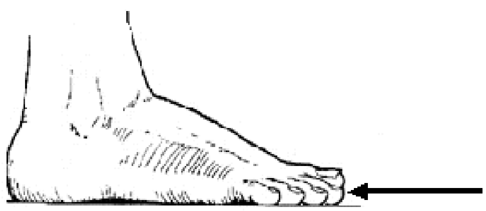
***Note**: For scans, an adhesive dot is placed on the fingernail with the center of the dot corresponding to the tip of the finger.*

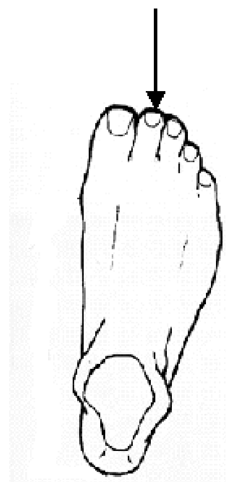


Landmark Name: Digit II, Left and Right
ISO Definition No. N/A
CAESAR Name: DIGIT II, LEFT AND RIGHT

Description: Tip of the second toe.

***Note**: For scans, an adhesive dot is placed on the tip of the toe, <u>not</u> on the toenail.*

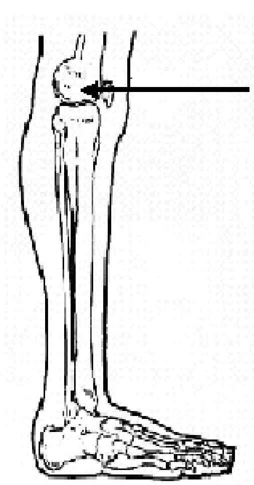


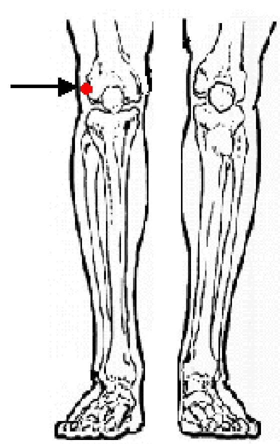


Landmark Name: Femoral Epicondyle, Lateral; Left and Right
ISO Definition No. N/A
CAESAR Name: FEMORAL EPICONDYLE, LATERAL; LEFT AND RIGHT

Description: Lateral point on the lateral epicondyle of the femur.

***Note**: Femoral epicondyles are marked while the subject is standing.*

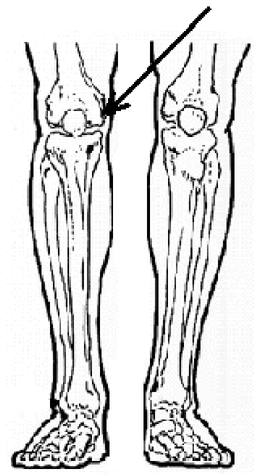


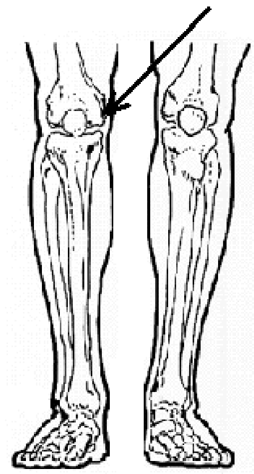


Landmark Name: Femoral Epicondyle, Medial; Left and Right
ISO Definition No. N/A
CAESAR Name: FEMORAL EPICONDYLE, MEDIAL; LEFT AND RIGHT

Description: Medial point on the medial epicondyle of the femur.

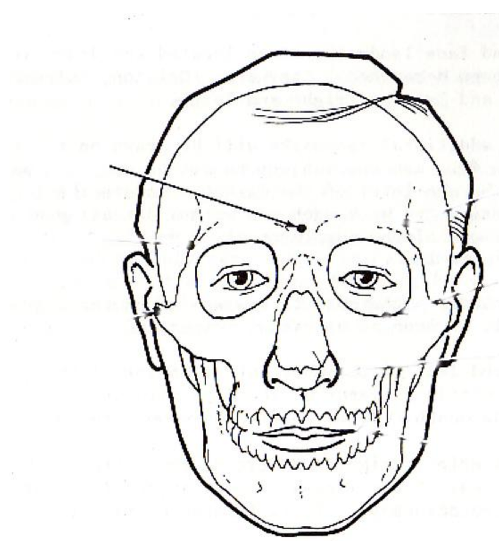
***Note**: Femoral epicondyles are marked while the subject is standing.*

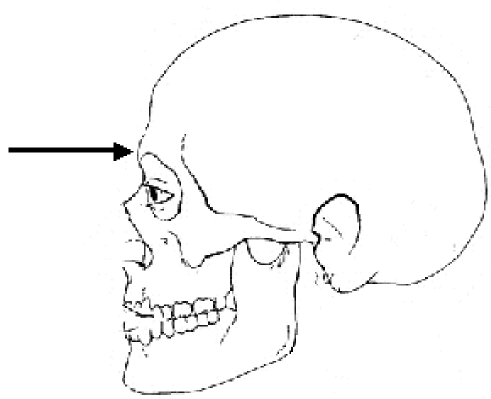




Landmark Name: GLABELLA
ISO Definition No. 2.2.9
CAESAR Name: Glabella

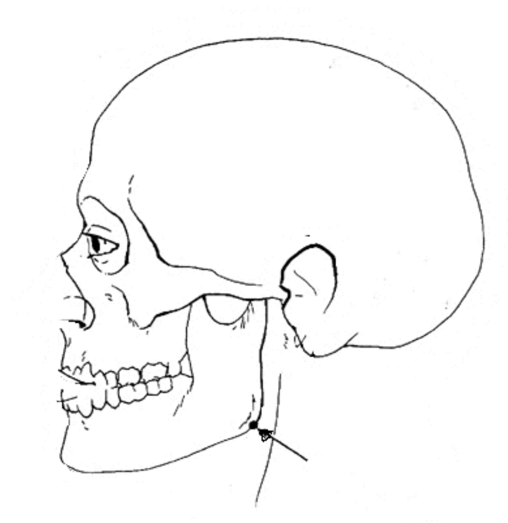
Description: Most anterior point of the forehead between the brow ridges in the midsagittal plane.





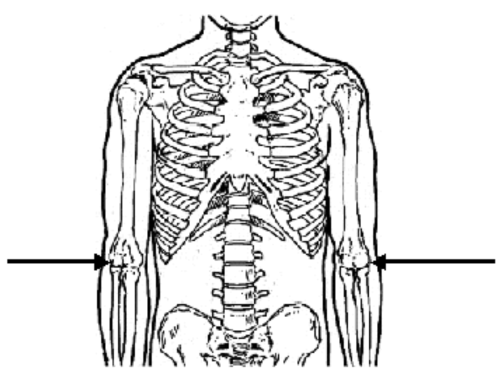
Landmark Name: Gonion
ISO Definition No. N/A
CAESAR Name: GONION

Description: Inferior, posterior tip of the gonial angle (the posterior point on the angle of the mandible, or jawbone).



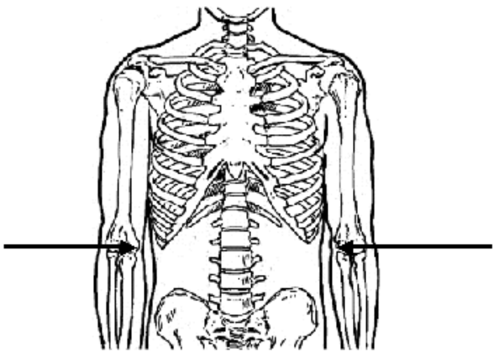
Landmark Name: Humeral Epicondyle, Lateral; Left and Right
ISO Definition No. N/A
CAESAR Name: HUMERAL EPICONDYLE, LATERAL; LEFT AND RIGHT

Description: Lateral point on the lateral epicondyle of the humerus, when the palm is facing the side of the body.



Landmark Name: Humeral Epicondyle, Medial; Left and Right
ISO Definition No. N/A
CAESAR Name: HUMERAL EPICONDYLE, MEDIAL; LEFT AND RIGHT

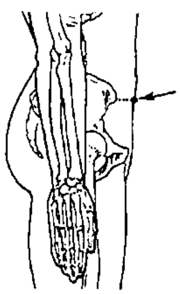
Description: Medial point on the medial epicondyle of the humerus, when the palm is facing the side of the body.

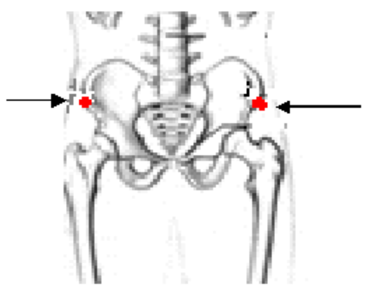


Landmark Name: Iliac Spine, Anterior, Superior; Left and Right
ISO Definition No. N/A
CAESAR Name: ILIAC SPINE, ANTERIOR, SUPERIOR; LEFT AND RIGHT

Description: Prominent, anterior point on the anterior rim of the ilia.

***Note**: The ilia are one of the three pair of bones that comprise the bony pelvis.*

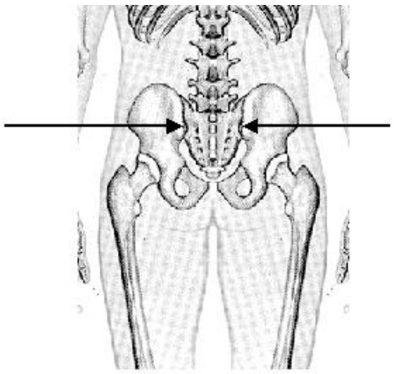




Landmark Name: Iliac Spine, Posterior, Superior; Left and Right
ISO Definition No. N/A
CAESAR Name: ILIAC SPINE, POSTERIOR, SUPERIOR; LEFT AND RIGHT

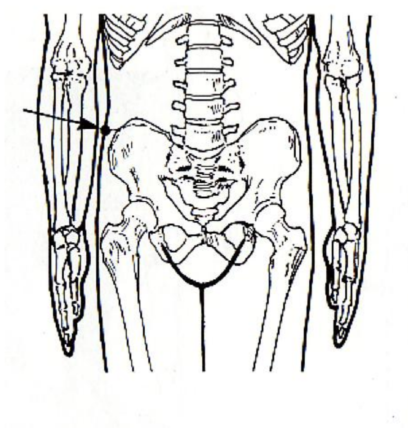
Description: Prominent point on the posterior superior spine of the ilium; a dimple often overlies this point.

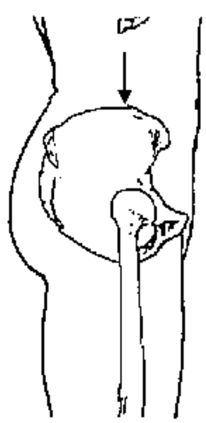
***Note**: The ilia are one of the three pair of bones that comprise the bony pelvis.*



Landmark Name: Iliocristale, Left and Right
ISO Definition No. N/A
CAESAR Name: ILIOCRISTALE, LEFT AND RIGHT

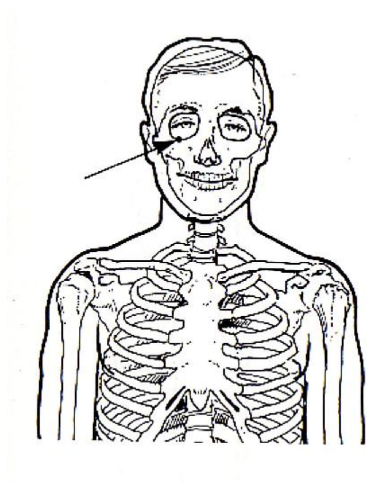
Description: Highest palpable point of the superior rim of the ilium in the mid-lateral line.





Landmark Name: Infraorbitale, Left and Right
ISO Definition No. N/A
CAESAR Name: INFRAORBITALE, LEFT AND RIGHT

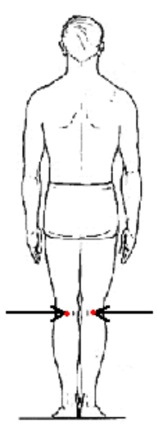
Description: Lowest point on the inferior margin of the orbit (the bony eye socket), marked directly inferior to pupil.



Landmark Name: Knee Crease, Left and Right
ISO Definition No. N/A
CAESAR Name: KNEE CREASE, LEFT AND RIGHT

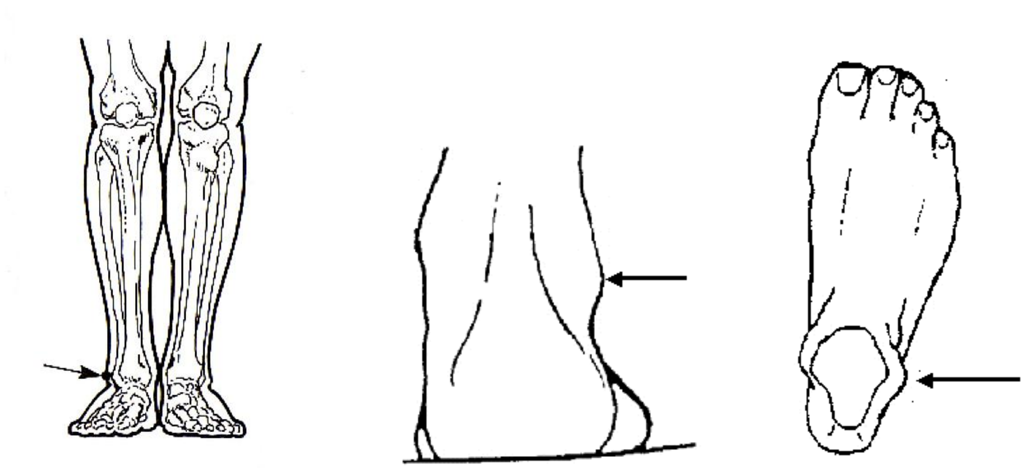
Description: Midpoint of the crease that runs medial to lateral on the posterior side of the knee.

Note: Knee crease is marked while the subject is standing.



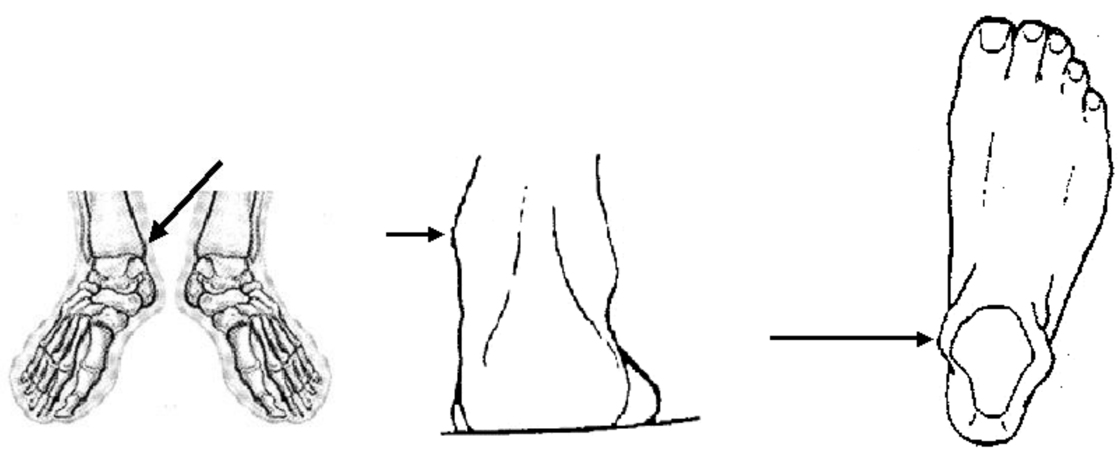
Landmark Name: Malleolus, Lateral; Left and Right
ISO Definition No. N/A
CAESAR Name: MALLEOLUS, LATERAL; LEFT AND RIGHT

Description: Lateral point on the distal fibular protrusion of the ankle.



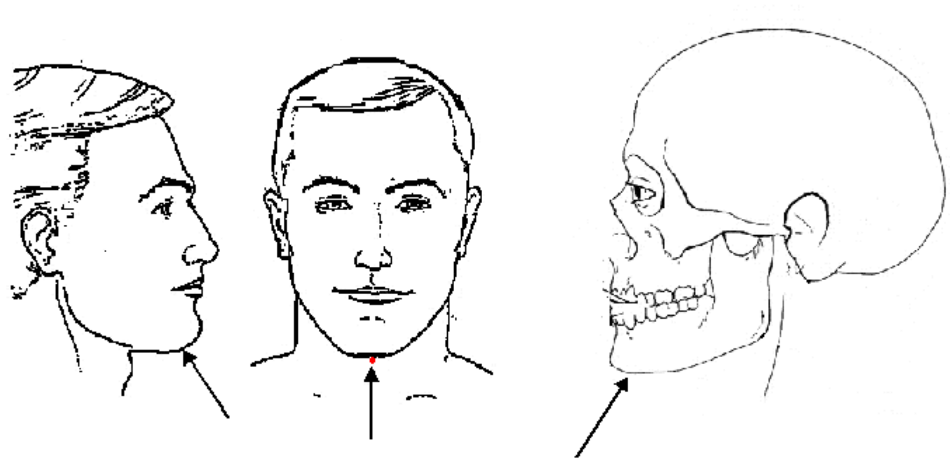
Landmark Name: Malleolus, Medial; Left and Right
ISO Definition No. N/A
CAESAR Name: MALLEOLUS, MEDIAL; LEFT AND RIGHT

Description: Medial point on the distal tibial protrusion of the ankle.



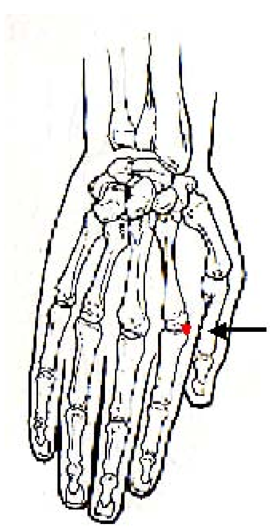
Landmark Name: MENTON; GNATHION
ISO Definition No. 2.2.16
CAESAR Name: Menton

Description: Lowest point of the tip of the chin in the midsagittal plane.



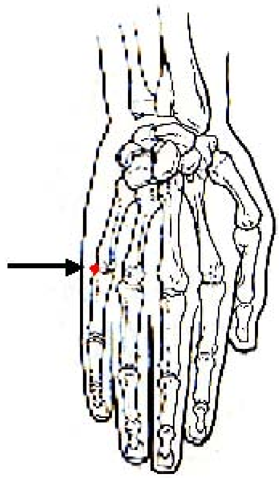
Landmark Name: Metacarpal-Phalangeal II, Right and Left
ISO Definition No. N/A
CAESAR Name: METACARPAL-PHALANGEAL II, RIGHT AND LEFT

Description: Prominent point on the lateral surface of the second metacarpal-phalangeal joint.



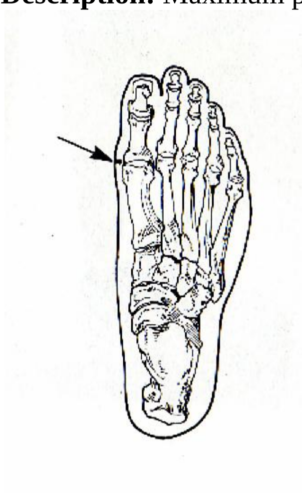
Landmark Name: Metacarpal-Phalangeal V, Right and Left
ISO Definition No. N/A
CAESAR Name: METACARPAL-PHALANGEAL V, RIGHT AND LEFT

Description: Prominent point on the lateral surface of the fifth metacarpal-phalangeal joint.



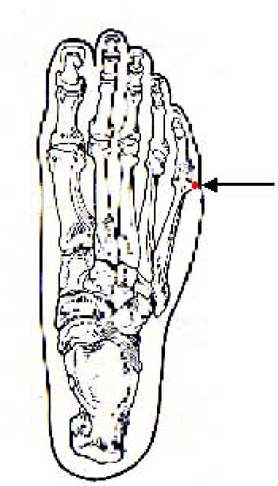
Landmark Name: Metatarsal-Phalangeal I, Right and Left
ISO Definition No. N/A
CAESAR Name: METATARSAL-PHALANGEAL I, RIGHT AND LEFT

Description: Maximum protrusion of the inside of the foot at the head of Metatarsus I.



Landmark Name: Metatarsal-Phalangeal V, Right and Left
ISO Definition No. N/A
CAESAR Name: METATARSAL-PHALANGEAL I, RIGHT AND LEFT

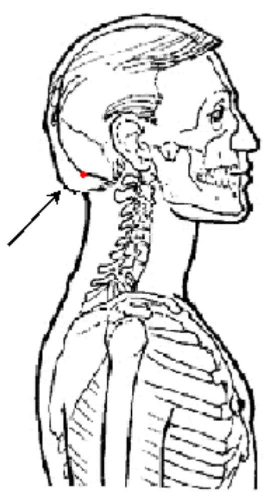
Description: Maximum protrusion of the outside of the foot at the head of Metatarsus V.



Landmark Name: Nuchale
ISO Definition No. N/A
CAESAR Name: NUCHALE

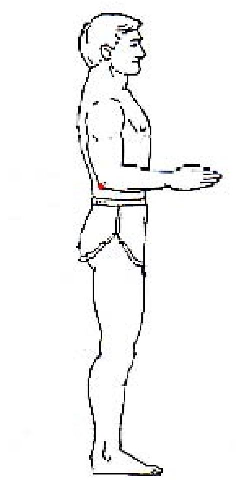
Description: Lowest point of the occiput that can be palpated among the nuchal muscles.

Note: *This point is often obscured by hair, and is marked in the midsagittal plane.*



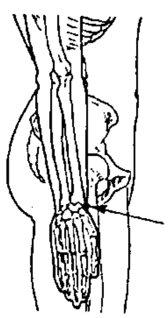
Landmark Name: Olecranon, Right and Left
ISO Definition No. N/A
CAESAR Name: OLECRANON, RIGHT AND LEFT

Description: Posterior point on the olecranon process of the ulna, marked with the elbow bent 90 degrees.



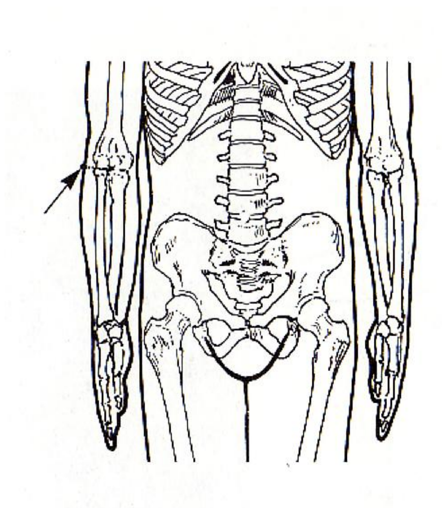
Landmark Name: Radial Styloid, Right and Left
ISO Definition No. N/A
CAESAR Name: RADIAL STYLOID, RIGHT AND LEFT

Description: Distal tip of the radius.



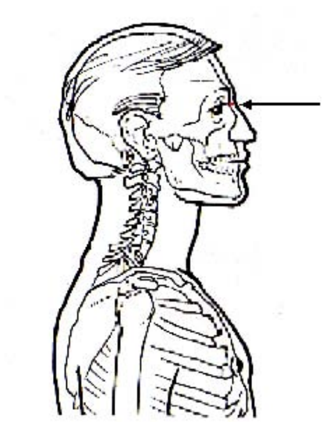
Landmark Name: Radiale, Right and Left
ISO Definition No. N/A
CAESAR Name: RADIALE, RIGHT AND LEFT

Description: Proximal point on the head of the radius, near the midpoint of the elbow on the lateral aspect of the arm.



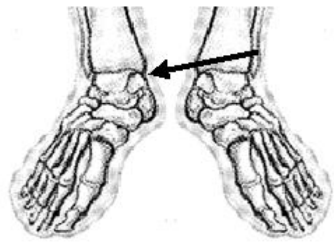
Landmark Name: NASION; SELLION
ISO Definition No. 2.2.19
CAESAR Name: Sellion

Description: Point of greatest indentation of the nasal root depression.



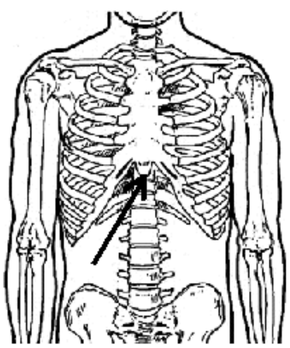
Landmark Name: Sphyrion, Right and Left
ISO Definition No. N/A
CAESAR Name: SPHYRION, RIGHT AND LEFT

Description: Distal point on the medial side of the tibia.



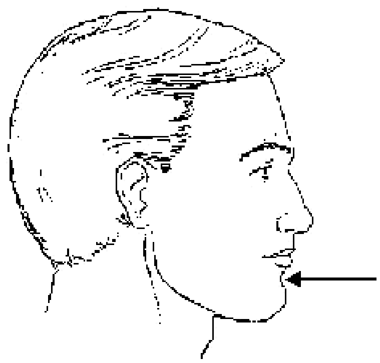
Landmark Name: Substernale
ISO Definition No. N/A
CAESAR Name: SUBSTERNALE

Description: Lowest palpable point on the sternum (breastbone).



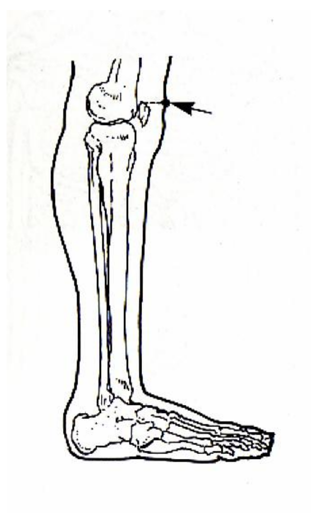
Landmark Name: Supramenton
ISO Definition No. N/A
CAESAR Name: SUPRAMENTON

Description: Point of greatest indentation of the mandibular symphysis, marked in the midsagittal plane.



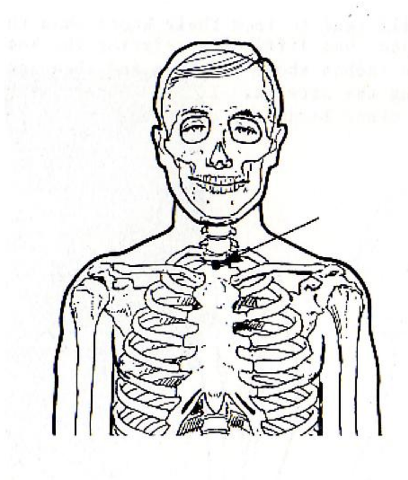
Landmark Name: Suprapatella
ISO Definition No. N/A
CAESAR Name: SUPRAPATELLA

Description: Top of the kneecap; the superior point on the patella while it is in the relaxed (loose) position.



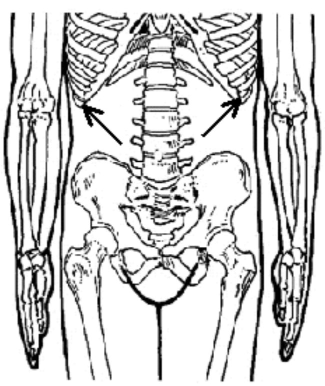
Landmark Name: Suprasternale
ISO Definition No. N/A
CAESAR Name: SUPRASTERNALE

Description: Highest palpable point on the sternum (breastbone).



Landmark Name: Tenth Rib, Right and Left
ISO Definition No. N/A
CAESAR Name: TENTH RIB, RIGHT AND LEFT

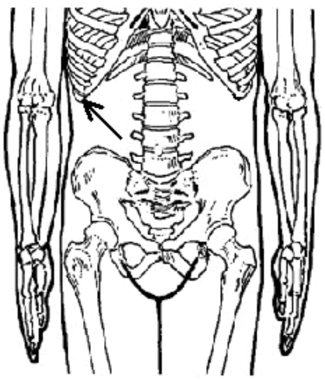
Description: Lowest palpable point on the inferior border of the Tenth Rib at the bottom of the rib cage.

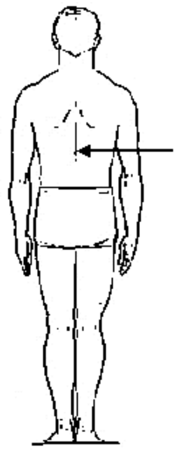


Landmark Name: Tenth Rib, Midspine
ISO Definition No. N/A
CAESAR Name: TENTH RIB, MIDSPINE

Description: Level of the right tenth rib (landmark), marked on the spine.

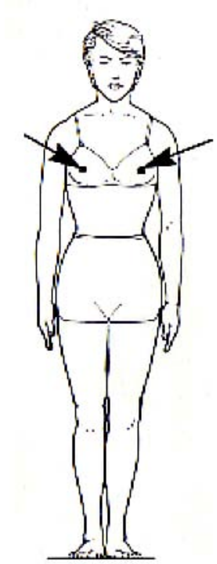
Note: *The anthropometer is used to mark the height of the landmark at midspine (on the spine in the midsagittal plane).*

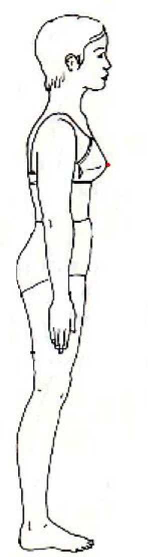




Landmark Name: Thelion/Bustpoint, Right and Left
ISO Definition No. N/A
CAESAR Name: THELION/BUSTPOINT, RIGHT AND LEFT

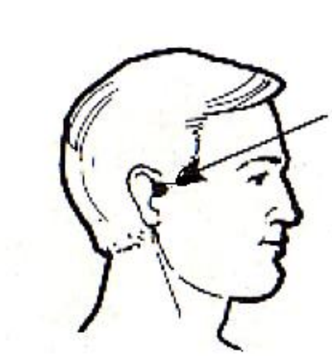
Description: Most anterior protrusion of the bra cup on women. Center of the nipple on men.





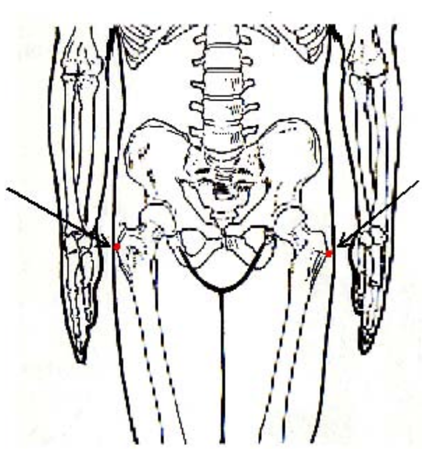
Landmark Name: TRAGION
ISO Definition No. 2.2.30
CAESAR Name: Tragion, Right and Left

Description: Notch just above the tragus (the small cartilaginous flap in front of the ear hole).



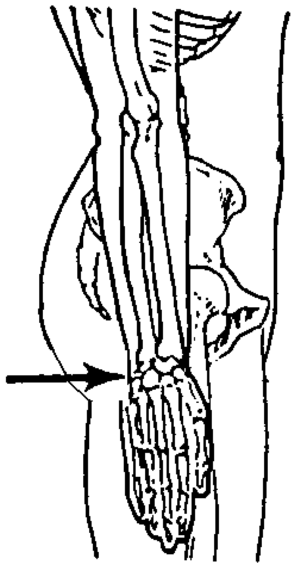
Landmark Name: Trochanterion, Right and Left
ISO Definition No. N/A
CAESAR Name: TROCHANTERION, RIGHT AND LEFT

Description: Top of the bony lateral protrusion of the proximal end of the femur.



Landmark Name: Ulnar Styloid, Right and Left
ISO Definition No. N/A
CAESAR Name: ULNAR STYLOID, RIGHT AND LEFT

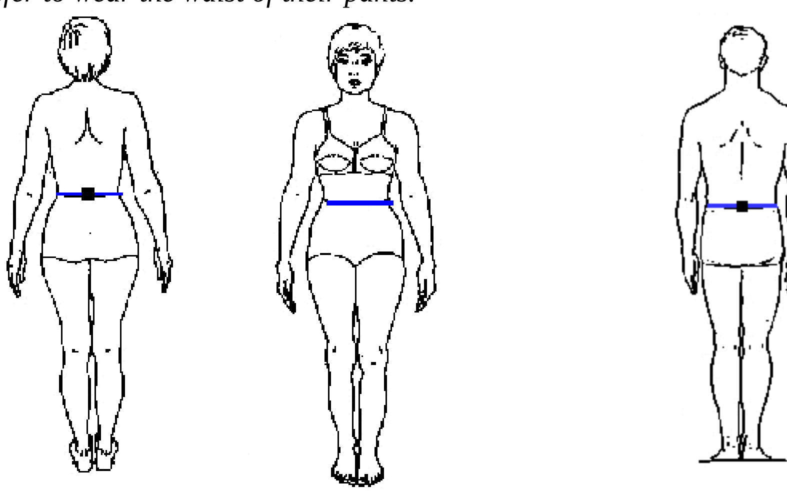
Description: Distal point of the ulna.



Landmark Name: Waist, Preferred, Posterior
ISO Definition No. N/A
CAESAR Name: WAIST, PREFERRED, POSTERIOR

Description: Level of the waist as marked on the subject's back in the midsagittal plane.

***Note**: Level of the waist is established by the subject placing an elastic band where he or she would prefer to wear the waist of their pants.*



APPENDIX D. FORMS

- Demographic Questionnaire

USAF Aircrew Survey Questionnaire

Subject Number: __________ **Date:** ________________

Birth Date: ____________ **Place of Birth (State or Country):** __________________

Age: __________ **Rank:** O-____ E-_____ **Sex:** M F

Race: 1) Asian/Pacific Islander 2) Black/African American 3) Caucasian/White
4) Spanish/Hispanic 5) (Other) __________________

Aircrew Position: __________________________

Type of Aircraft Currently Flying: __________________________

Type of Aircraft Most Experienced: __________________________

Total Flight Time: __________________________

Equipment Size: (circle both size and length if applicable)

Flight Suit (CWU-27/P)
Size: 32 34 36 38 40 42 44 46 48 50 52
Length: Short Regular Long

(Women's Coveralls Type II Class I)
Size: 30 32 34 36 38 40 42 44
Length: MS MR ML WS WR WL

Cold Weather Flight Coveralls (CWU-64/P): **Size-** 32 34 36 38 40 42 44 46 48 *Don't Know*
Length- Short Regular Long

Anti G-Suit (CSU-13B/P): N/A **Size -** S M L *Don't Know*
Length- Regular Long X-Long

Anti G-Vest (CSU-17/P): N/A S M L XL *Don't Know*

Torso (Flight) Harness: N/A PCU – 15A/P PCU-16A/P *Don't Know*

SRU-21/P Survival Vest: N/A **Size –** M L *Don't Know*

Flight Jacket, Summer/Winter (CWU 36/P, 45/P): S M L XL *Don't Know*

Flight Boot (FWU-8/P): Size- 6 6½ 7 7½ 8 8½ 9 9½ 10 10½ 11 11½ 12 12½ *Don't Know*
Width- Regular Wide

Flight Glove (GS/FRP-2): 4 5 6 7 8 9 10 11 12 *Don't Know*

Cold/Wet Protective Flight Glove (HAU-15/P): 5 6 7 8 9 10 11 *Don't Know*

Extreme Cold Weather Trousers (CWU 18/P): 28 30 32 34 36 38 40 42 *Don't Know*

Helmet (HGU-55/P L/W): N/A M L XL *Don't Know*

(CONTINUED ON REVERSE SIDE)

Mask: N/A *Don't Know*

MBU-12/P: Short Regular Long X-Long

MBU-5/P (Pressure Demand Breathing):

Regular-Narrow Regular-Wide Long-Narrow Short-Narrow

MBU-20/P (Combat Edge):

Small-Narrow Medium-Wide Medium-Narrow Large-Wide

Aircrew Armor: N/A XS, S M L XL *Don't Know*

Anti Exposure Items: N/A *Don't Know* **(Circle one Size below)**

CWU-74/P Coveralls
CWU-62B/P Coveralls
CWU-62C/P Coveralls
CWU-23/Liner

	Small	Medium	Large	X-Large
Short	1	4	7	10
Regular	2	5	8	11
Long	3	6	9	12

Have any of your flight clothes been altered to fit better? Y N

If so,

- Which article(s) of clothing were altered? **1)** ____________________

2) ____________________

3) ____________________

- Which part(s) of the clothing were altered? **1)** ____________________

2) ____________________

3) ____________________

- Anthropometrics dimensions record form

2008 USAF Aircrew Survey: AFRL/RHPA Anthropometry Laboratory

Date		Subject Number	
Last Name		First Name	
Middle Initial		Rank	
Sex			
Measurer			
Recorder			

Neck Base Circ		Vertical Trunk Circ	
Weight		Buttock Circ	
Span		Buttock Circ Height	
Stature		Hip Circ Max	
Cervicale Height		Hip Circ Max Height	
Axilla Height		Thigh Circ Max	
Crotch Height		Calf Circ	
Thumb Tip Reach 1		Ankle Circ	
Thumb Tip Reach 2		Foot Length	
Thumb Tip Reach 3		Shoulder (Bideltoid) Breadth	
Forearm Circ, Flexed		Sitting Height	
Bicep Circ, Flexed		Eye Height Sitting	
Arm Length (Spine-Shoulder)		Acromial Height Sitting	
Arm Length (Spine-Elbow)		Elbow Height Sitting	
Arm Length (Spine-Wrist)		Thigh Clearance	
Armscye Circumference		Knee Height Sitting	
Spine to Scye		Popliteal Height	
Spine to Wrist 2		Hand Circ	
Chest Girth (Chest Circ at Scye)		Neck Circumference	
Bust/Chest Circ		Head Circ	
Waist Circ at Natural Indent		Head Length	
Waist Height at Natural Indent		Bizygomatic Breadth	
Waist Circ at Omphalion		Head Breadth	
Waist Height at Omphalion		Chest Depth	
Waist Circ Preferred		Abdomen Depth	
Waist Height, Preferred		Buttock Popliteal Length	
Neck Base to Suprasternale		Buttock Knee Length	
Suprasternale to Anterior Waist Pref		Hip Breadth Sitting	
Anterior to Posterior Waist Pref		Face Length	
Posterior Waist Pref to Cervicale		Hand Length	

Notes: Notes:

- Fit evaluation/ratings record form

	Capable of Mobility in Scan Garments (Circle) Yes No							Subject Number :		
	Fit Evaluation				Example	First	Second	Third	Fourth	Fifth
	Assessment	Type (Landmark)	Posture	Assesse	Size X					
Mobility	Hand and arm movement	Ordinal Scale	Standing	Subject*	3					
	Torso length	Ordinal Scale	Standing	Subject*	3					
	Leg movement (0.65m step)	Pass/Mrgnl Pass/Fail	Standing	Fitter	p					
	Torso Movement (Bootlaces)	Pass/Mrgnl Pass/Fail	Standing	Fitter	p					
	Head Movement	Pass/Mrgnl Pass/Fail	Seated	Fitter	p					
Safety	Arm Restraint	Direction*	Seated	Fitter	3					
	Sleeve length	Line (Ulna Styloid)	Seated	Fitter	1.2					
Location	Neck and Collar	Line (Suprasternale)	Standing	Fitter	0.4					
	Shoulder	Line (Acromion)	Standing	Fitter	0.5					
	Waist Height	Line (Omphalio)	Standing	Fitter	1					
	Leg Length	Line (Lateral Malleolous)	Standing	Fitter	6.6					
	Armscye	Ease (Axilla)	Standing	Fitter	1.5 , 1.75	___ , ___	___ , ___	___ , ___	___ , ___	___ , ___
	Chest	Ease (Thelion Level)	Standing	Fitter	0.5 , 0.75	___ , ___	___ , ___	___ , ___	___ , ___	___ , ___
	Waist Height	Ease (Omphalion Level)	Standing	Fitter	1.0 , 0.75	___ , ___	___ , ___	___ , ___	___ , ___	___ , ___
	Hip	Ease (Max Hip level)	Standing	Fitter	0.75 , 1.0	___ , ___	___ , ___	___ , ___	___ , ___	___ , ___
	Crotch	Ease (PSIS level)	Standing	Fitter	1.25	___ , ___	___ , ___	___ , ___	___ , ___	___ , ___
Overall	Subject's evaluation	Ordinal Scale	Standing	Subject**						

*Subject assessment	**Subject assessment(Overall)	*direction	*Measurements
1: Too tight, mobility is restricted	1. Cannot wear all day	1: Too high, 12 o'clock	High, short--> negative value
2: Tight, but wearable all day	2. Tight or loose but could wear all day	2: Marginally high, 11 o'clock	Low, Loose--> positive value
3: Good and comfortible	3. OK fit but not great	3: Good 10:30	
4: Loose, but wearable all day	4. Really good	4: Marginally low, 10 o'clock	
5: Too loose, mobility is restricted		5: Too low, 9 o'clock	

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